KARL POPPER'S REALISM AND THE PHILOSOPHICAL SCHISM IN MODERN SCIENCE

By

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This dissertation is dedicated to
the late Robert Long. His sensitivity
and depth of thought will be not forgotten.

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This dissertation describes and assesses Karl Popper's commonsense realism. The evaluation focuses upon his arguments against nonrealism in modern physics rather than his purely philosophical arguments. Motivated by a few central concepts, Popper presented a detailed critique of the orthodox interpretation of physics. He created a "quantum mechanics without an observer" based upon an "epistemology without a subject."

Popper believed that certain philosophical presuppositions were necessary for progressive and objective science. He claimed that a "serious crisis exists in modern physics" due to the suspension of realism. Popper subsequently presented an elaborate reinterpretation of quantum theory in attempt to reinstate a realistic and objectivist conceptual framework. He also supported the EPR thought experiment which he was convinced demonstrated the incompleteness of quantum theory and the subsequent unnecessary nonrealistic interpretation.

Important presuppositions and contraints of Popper's realism not explicit in his purely philosophical work are manifested in his philosophical physics. The EPR test proposal crystallized his argument against positivism in physics. Thus, in light of the recent testing of the EPR paradox, I evaluate Popper's philosophical presuppositions and inquire whether classical realism needs revision.

The dissertation's goal is this assessment of Popper's concepts underlying his attack upon modern physics. Rather than an abstract analysis of his concepts, I assess them in the context of the current quantum theoretical debates and recent testing of the EPR proposal.

The dissertation is in the "history of ideas" style. I describe Popper's general philosophy of science, the challenge to his realism by modern physics and the Copenhagen Interpretation, Popper's realisic reinterpretation of quantum theory and the inadequacies of his project (especially in light of the recent EPR results). I then evaluate his commonsense realism on the basis of his presuppositions of his project. I conclude that Popper's constraints were norms derived from classical science and were overly dependent upon intuitive, traditional notions. These constraints then can be incompatible with counter-intuitive notions of contemporary theoretical science. I also suggest that Popper's ontological dichotomies are biased by classical notions.

INTRODUCTION

For Karl Popper, modern science represented the highest achievement of human knowledge. In addition to its critical method of conjectures and refutations, Popper believed that certain philosophical premises were essential for the dynamic growth of science. Accordingly, the task of philosophy was the clarification of the most effective methods and premises that ameliorated science. Popper was convinced that a deviation from the basic philosophical premises of objective knowledge could seriously impair science.

Popper, along with many other philosophers and physicists, believed that a significant crisis indeed was developing in modern physics due to the suspension of various premises. A new interpretation of physics, commonly called the Copenhagen Interpretation, broke with the philosophical presuppositions that classical physics successfully utilized for centuries. Thus, Popper's intense immersion in philosophical physics was not motivated by mere intellectual curiosity but a grave concern about scientific progress.

> A very serious situation has arisen. The general antirationalist atmosphere which has become a major menace of our time, and which to combat is the duty of every thinker who cares for the traditions of our civilization, has led to a most serious deterioration of the standards of scientific discussion. It is all connected with the difficulties of the [quantum] theory--or rather, not so much with the difficulties of the theory itself as with the difficulties of the new techniques which threaten to engulf the theory.[1]

Popper believed that realism was an essential premise for progressive science. He was convinced that science requires the belief that it describes and explains a physical world autonomous from human observation or constitution. Without this premise, scientific descriptions and laws would represent only a set of "recipes" for predicting various phenomena devoid of genuine truth about physical reality. Popper thought nonrealistic science would be "trivialized" since the most successful theory could not be considered an explanation and illumination of natural laws but only the mere correlation of observed values and laboratory manipulations.

While Popper elaborated a particular doctrine of realism which he designated "commonsense realism," he avoided a precise definition of realism. Consequently, in this dissertation I will use Bernard d'Espagnat's definition of realism, which does not contradict Popper's treatment of realism.

> Realism [is] . . . the doctrine that regularities in observed phenomena are caused by some physical reality whose existence is independent of human observers.[2]

D'Espagnat's definition is sensitive to the specific problems that arose in modern physics concerning the suspension of realism in classical physics. Classical realism became problematic in modern physics because atomic events and the corresponding objects were now considered inextricably linked to the observational conditions and processes. Various empirical postulates and discoveries in quantum mechanics impugned the belief in the unrestricted autonomy of objects from the means of observation.

The term "positivism" will be used in contrast to d'Espagnat's definition of realism. This form of positivism then signifies the belief that the regularities of observed phenomena are not independent of human observation. Positivism in this empirical context is not synonymous with logical positivism in philosophy. Nevertheless, both positions avoid reference to a "real, natural world" beyond observation, measurement and "appearance." Therefore, scientific or philosophical statements that appeal to the reality of "the unmeasured" are meaningless.

The nonrealist views that Popper vehemently opposed in modern science emerged independently of logical positivism. My dissertation attempts to evaluate the premisses and constraints of Popper's realism as manifested in his attack upon the positivism. Popper explicitly enunciated various premisses in his project to reinstate realism in modern physics that were not formulated in his "purely philosophical" writings. He subsequently offered a concrete realist position with empirical consequences, rather than an entirely conceptual doctrine.

In Chapter Two, I will describe several significant empirical discoveries and postulates in atomic theory that encouraged the suspension of realism. These principles often linked the observed phenomena to the conditions, processes and activities of observation. For example, it was established that observation unavoidably disturbed minute atomic systems and that the energy used in measurement altered the object. Upon measurement (or some other interaction with a macroscopic state) the superposition "collapsed" into one determinate state. Many scientists concluded that the character of measurement

partially determined the (properites of the) observed entity. Niels Bohr consequently advocated the view that it is impossible to conceptually and physically demarcate the observed object from the conditions of observations. Bohr spoke of an "experimental unity" or "wholeness" that unified the measured objects to the domain and framework of observation.

In classical physics, the effects of observation were controllable and accountable to the extent that empirical knowledge was considered "observer-free." For example, when a liquid's temperature is measured, the thermometer's effect (i.e., its own temperature) can be accounted for and is controllable. The disturbance of this measurement can be "annulled" with respect to its measured value. The ideal example in classical physics was astronomical measurement where the object received a negligible disturbance by observation. Thus, measurement in classical physics, as in these simple examples, was generally unproblematic. Since the observed effects were known and accountable, the (state of the) object in classical physics was considered independent from the observation. Accordingly, Putnam stated that "measurement [in Newtonian mechanics] <u>plays no fundamental role in physical theory as such</u>."[3] Since the object was considered physically independent from the observation, realism was a common view of classical physicists. That is, the regularities in observed phenomena were caused by a physical reality that was independent from human observation. Indeed, classical physicists possessed no empirical grounds to doubt this view.

In the early 20th century, physicists discovered empirical reasons to controvert this simple and "natural" premise. Whereas the "actual properties" of a classical system were considered intrinsic to the system, the observable properties of an atomic or quantum system reflected the experimental arrangement. The essential properties then could be the result of experimental alterations and choices. A key notion in classical realism, the autonomy of objects from observation, was consequently challenged. The Copenhagen Interpretation of modern physics explicitly embraced a positivism that many philosophers, such as Popper, found detrimental. As Alistair Rae summarized,

> We see here the central idea of the Copenhagen Interpretation: a quantity can be considered real only if it has been measured or if it is in a measurement situation when the outcome of the experiment is predictable.[4]

Werner Heisenberg, one of the founders of quantum theory, more dramatically concluded that (the traditional notion of) "objective reality has evaporated." Whereas "nature" was the general explanadum in classical science, Heisenberg thought that nature now signifies only the relation of the observable to the methods, means and conditions of observation. Atomic physics then represented the termination of classical ideals for many scientists. Heisenberg added,

> It is . . . not by chance that "objective reality" is limited to the realm of what Man can describe simply in terms of space or time. At this point, we realize the simple fact that natural science is not Nature itself but a part of the relation between Man and Nature, and therefore is dependent on Man.[5]

Popper abhored the Copenhagen Interpretation's view that any unmeasured properties were considered unreal and meaningless. He thought that this view would cripple scientific growth (i.e., the

creation of verisimilar theories about objective reality.) Popper concluded that the Copenhagen Interpretation was a violation of the requisite premisses of objective science. In an attempt to reinstate classical realism and other "objectivist" principles, Popper elaborated a detailed reinterpretation of modern physics. In Chapter Three, I summarize his ambitious project that strove to "exorcise the observer" from quantum theory. With the eradication of the observer, or the positivist dependence of the observed upon observation, Popper believed the primary source of nonrealism would collapse. Popper proposed the propensity theory as a objectivist and realist interpretation of quantum theory in lieu of the Copenhagen Interpretation. Popper also offered several thought-experiments which he believed demonstrated fallacies within the Copenhagen Interpretation.

Popper's philosophical physics is not the primary focus of the dissertation but rather the conceptual premises and contraints underlying his project. His philosophical treatment of physics manifested key elements and presuppositions of his commonsense realism that were not explicit in his purely philosophical writings. <u>I believe that these presuppositions show a fundamental inadequacy of Popper's commonsense realism and help to demonstrate general limitations within his ontology</u>.

For example, a major component of Popper's argument against the Copenhagen Interpretation was a far-reaching thought-experiment proposed by Einstein, Podolsky and Rosen in 1935. The EPR thought-experiment explicitly attacked the Copenhagen Interpretation and its view of "indeterminate-until-observed" reality. Popper embraced the EPR

thought-experiment as the clearest and most cogent refutation of the empirical basis of positivism in physics. Decades before the recent laboratory testing of the EPR proposal, Popper was convinced that their thought-experiment revealed an ineluctable paradox demonstrating the fallacies and incompleteness of the Copenhagen Interpretation. The EPR argument crystallized Popper's argument against the "unnecessary and dangerous" positivism in physics. More importantly, Popper's commitment to the EPR experiment revealed significant dimensions of his commonsense realism.

One major aspect of the EPR argument was the attempt to demonstrate that unmeasured properties were real and determinate. Popper and Einstein strongly detested the notion that atomic systems were in <u>indeterminate</u> states until measured. Popper was appalled at the positivist conclusion that "reality" was dependent upon the human act of observation. Yet, many physicists and philosophers thought that the empirical basis for this view was undeniable. In fact, quantum theory has been regarded as a major transformation of traditional objectivist and realist epistemologies. Richard Schlegel, a contemporary theoretical physicist, epitomized this "revolution" as follows:

> For the quantum systems, there are . . ., in contrast to a classical object, notable differences with respect to measurement. . . . The observed state of the system is generally determined in the act of measurement; hence, we have only the system to refer to as existing before the measurement, not the entity as measured. <u>Here we have a departure from the natural philosophy of classical physics that entails an alteration in virtually every aspect of man's conception of his external world. Indeed, nowhere in the Western philosophical tradition, beginning with the pre-Socratic speculations, is there any indication of determination, in the act of observation, of the particular values of the primary (dynamical) properties of that which is observed</u>. There are those philosophies, as that of Bishop

> Berkeley or extreme positivism, which locates existence in perception, but they do so for the entire natural object. In contrast almost all quantum theorists regard the total system as having no observer-dependence with respect to existence prior to observation even though its properties observed are dependent. . . . In a word, classically the object has its observed dynamical properties independently of their being observed, whereas quantum mechanically, generally the system has no unique set of properties before observation and such a set is created only by the observing act.[6] (added emphasis)

The EPR thought-experiment then was an attempt to undermine the empirical impetus for this radically new philosophical interpretation.

Although the proponents of the EPR proposal sought a refutation of the Copenhagen Interpretation, the actual results impugned their own presuppositions and unambiguously affirmed the Copenhagen Interpretation. Popper was greatly "surprised" at the results and lacked a coherent explanation.[7] The results signify the limitations of several fundamental classical concepts and presuppositions. As Abner Shimony recently remarked, "The [EPR] experimental results reveal more clearly than ever that we live in a strange, "quantum world" that defies comfortable, commonsense interpretation."[8] Whereas Popper's commonsense realism and his subsequent philosophical physics was clearly antithetical to quantum theory, the recent EPR testing clearly demonstrated the inadequacies of his constraints applied to empirical science.

In Chapter Four, I will summarize the weaknesses and limitations of Popper's endeavor to refute nonrealism in modern physics. The EPR results will play a large role in arguing for the classical, traditional character of Popper' premises. More precisely, it appears that Popper's constraints and "requisites for objective science" were norms derived

from classical physics. Chapter Four then is the basis for questioning whether commonsense realism is a progressive understanding of science.

In the final chapter, I will attempt to evaluate the premises of Popper's realism. I will argue that the central motivation for Popper's philosophical physics, i.e., the fear of a scientific crisis, was unwarranted. I question whether the suspension of realism has any significant impact on scientific progress. On the contrary, the rigid adherence to intuitive, commonsense contraints could impede the investigation of counterintuitive concepts (such as several concepts in quantum theory). Accordingly, I support Paul Feyerabend's critique of rigid realism that is empirically insensitive. The impairment of scientific theories and postulates by stringent ideological commitments to commonsense premises in fact weakens the arguments for the necessity of realism. Historically, scientists often use nonrealistic or instrumental strategies and postulates. A coerced realistic interpretations in such cases would be artificial and dogmatic.

I then suggest that if some form of realism is desirable or philosophically unavoidable, then it must be more compatible with the counterintuitive notions that often emerge within <u>theoretical</u> science. In addition, any concomitant realistic presuppositions should not be dictated by norms derived by formerly successful theories (that may inhibit the new theory). In this vein, various theoretical physicists such as Bernard d'Espagnat and David Bohm have advocated forms of realism that explicitly encourage nonclassical and counterintuitive physical notions.

I conclude the final chapter with a brief analysis of Popper's ontological distinctions based upon the presuppositions revealed in his attack upon positivism in modern science. I argue that his dichotomies and demarcations purportedly necessary for objective science are actually norms derived from classical science. Popper's ontology creates an unnecessary standard that successful theories or interpretations, such as the Copenhagen Interpretation, may not attain. For example, Popper's epistemological dichotomy between the (properities of the) object and the conditions of observation was a (quasi) _a priori_ norm biased by classical concepts. Thus, Popper's three-world ontology cannot clarify scientific theories outside of the classical domain.

Finally, Popper's philosophy of science represents a paradox. Popper advocated the need for bold, revolutionary theories and ideas and argued for the fallibility of all scientific and philosophical theories and concepts. He explicitly stated that commonsense notions need "enlightenment" and that these fundamental ideas must be continuously improved. Yet, when Popper encountered the abandonment of certain philosophical principles, he believed a crisis in science was transpiring. Due to what he believed was a rampant subjectivism in philosophy, he constucted an "epistemology without a subject" to reinstate classical objectivism. Similarly, to counter the suspension of classical realism, he advocated a "quantum mechanics without an observer" to maintain traditional presuppositions. I contend then that despite Popper's _progressive_ policy of fallible conjectures and refutations, he adopted a _conservative_ ontology and epistemology that does not clarify nonclassical science. In fact, the embrace of

Popperian philosophical presuppositions and constraints by theoretical scientists could impair the development of successful research programs such as the Copenhagen Interpretation. Consequently, if realism is conceptually necessary or desirable, it appears that Popper's commonsense realism is not a viable candidate for a modern theory of knowledge.

Notes

[1] Karl Popper, Quantum Theory and the Schism in Modern Physics (Totawa, New Jersey: Rowan and Littlefield, 1982) 156.

[2] Bernard d'Espagnat, "Quantum Theory and Reality," Scientific American Nov. 1979: 128.

[3] Hilary Putnam, "A Philosopher Looks at Quantum Mechanics," Beyond the Edge of Certainty, ed. R. G. Colodny (Englewood Cliffs, New Jersey: Prentice-Hall, 1965) 79.

[4] Alistair Rae, Quantum Theory: Illusion or Reality? (Cambridge: Cambridge University Press, 1986) 51.

[5] Werner Heisenberg, Physics and Philosophy (New York: Harper and Row, 1958) 81.

[6] Richard Schlegel, Superposition and Interaction (Chicago: U of Chicago P, 1980) 166.

[7] Karl Popper, op.cit., 25.

[8] Abner Shimony, "The Reality of the Quantum World," Scientific American Jan. 1988: 46.

CHAPTER ONE

POPPER'S GENERAL PHILOSOPHY OF SCIENCE

Initial Premises of Popper's Thought

Popper's specific treatment of the suspension of realism in modern science should be discussed against the background of his general philosophy of science. Popper's specific project to reinstate realism in modern science was a natural extension of his broader philosophy of science. Popper's theory of objective knowledge attempted to overcome modern philosophy's subjectivist or "belief philosophy" foundations. Likewise, his treatment of modern physics strove to offset positivism and instrumentalism in the current interpretation of physical knowledge. Popper wanted to maintain the realism of classical science and therefore criticized the new role of the observer in quantum physics. Popper's attack upon the Copenhagen Interpretation, the dominant view of atomic physics, is understandable and predictable once we consider his views concerning realism, instrumentalism and objective, "third world" knowledge. Accordingly, Popper's specific "physics without an observer" originated from his general theory of "knowledge without a subject."

Popper strove to locate the precise characteristics of science that led to its prolific results. He asked: why is science so successful in contrast to nonscience, primitive (inchoate) science or pseudo-science? Why does science continually succeed? Popper reduced this question to

that of drawing a distinction between genuine science and pseudo-science. The so-called "demarcation problem" led him to the fundamental tenet of his epistemology: falsifiability.

What indeed distinguishes an actual practice of science, e.g., astronomy, from a "pseudo-practice," e.g., astrology? Both observe stellar configurations, give explanations of natural phenomena and make predictions based upon purported causal connections. Both include metaphysical elements not directly observable or verifiable. Both also involve varying degrees of mathematics. What, then, truly signifies the demarcation of science and nonscience? Popper's answer was concise and significant: "The criterion of the scientific status of a theory is its falsifiability, or refutability, or testability."[1]

For Popper, the nature of scientific explanation is the proposal of tentative theories that are accessible to clear and severe testing, i.e., to falsification. Genuine science proposes nondogmatic theories as conjectures that must be challenged and refuted if possible. Good scientific theories possess many testable elements and thus are vulnerable. In fact, the more susceptible to refutation, the better the theory. It is important to notice Popper's emphasis upon refutability, rather than upon confirmation. This emphasis is simply due to the misleading nature of confirmation, i.e., practically all theories have huge numbers of confirming instances and examples. For example, geocentric astronomy possessed hundreds of confirming instances, yet the theory was falsified. Thus, confirmations do not guarantee truth. Newton-Smith similarly stated, "No set of observations, no matter how selected, can increase the probability of a generalization which entails

them."[2] Popper's main point was inductive: the number of confirming instances can approach infinity, and yet, a singular contradictory instance may destroy the universal proposition.

For Popper, the essential activity of science was the rigorous disconfirmation of hypotheses. Thus, Popper's view of science avoided the problem of inductive confirmation and rested on an unproblematic form of deduction. The tentative conjecture forms the major premise (e.g., Newton's theory predicts the orbit of Mercury to be thus-and-so.) This is followed by a negating minor premise (e.g., the orbit is irregular and not as predicted by Newton.) By *modus tollens*, the refutation is established.[3]

Popper held that irrefutability is not a virtue of a theory. A "good" theory is vulnerable, i.e., testable. The lengthy existence and success of a position actually may signify its repression of alternative candidates rather than any inherent accuracy. The lifespan of astrology then signifies little.

> Astrologers were greatly impressed and misled, by what they believed to be confirming evidence--so much so that they were quite unimpressed by any unfavorable evidence. Moreover, by making their interpretations and prophecies sufficiently vague they were able to explain away anything that might have been a refutation of the theory had the prophecies been more precise. In order to escape falsification they destroyed the testability of their theory. It is a typical soothsayer's trick to predict things so vaguely that the prediction can hardly fail; . . . they become irrefutable.[4]

Falsifiability then clarified the problem of demarcation, namely, the differentiation of science and nonscience. Falsifibility did not require that scientific hypotheses must be elaborate and systematic theories. Hypotheses rather often begin with "wild, myth-like"

conjectures. The requirement upon hypotheses is an openness to criticism and rejection. Popper remarked,

> . . . there is no more rational procedure than the method of trial and error--of conjecture and refutation; of boldly proposing theories; of trying our best to show that these are erroneous and <u>of accepting them tentatively if our critical efforts are unsuccessful</u>.[5] (emphasis added)

The emphasized phrase designated for Popper which theories are noteworthy: theories that have withstood rigorous criticism. Further, the most productive theory will never transcend the status of "tentative conjecture" to attain "truth." This is impossible for a finite science. The most potent current theories may be devastated by future inquiry.

Realism and Instrumentalism

> The realization that natural science is not indubitable *episteme* (*scientia*) has led to the view that it is *techne* (techniques, art, technologies); but the proper view, I believe, is that it consists of *doxai* (opinions, conjectures) controlled by critical discussion as well as by experimental *techne*.[6]

Popper was highly critical of the emergence of instrumentalism and positivism (defined below) in physics and believed that science was impaired by instrumentalism. Popper's subsequent arduous project against nonrealism in science then was motivated by a desire to resurrect critical premises of successful science.

Popper distinguished three theories of knowledge. The three tenets of the first view, essentialism, will serve to distinguish the other two views, instrumentalism and critical rationalism. The three tenets are:

> (1) The scientist aims at finding a true theory or description of the world (and especially of its regularities or "laws"), which shall also be an explanation of the observable facts. (2) The scientist can succeed in finally establishing the truth of such theories beyond all reasonable doubt. (3) The best, the truly scientific theories, describe the "essences" or the "essential natures" of things--the realities which lie behind the appearances.[7]

Instrumentalists deny all three tenets of essentialism since essences and truth are (apparently) unattainable. The third view of knowledge, Popper's critical rationalism, upholds only the first tenet; i.e., Popper agrees that science aims at finding a true theory of the world.

The first tenet may seem contradictory to Popper's view. Popper denies that a conjecture could ever arrive at apodictic truth (the second tenet). Doesn't this contradict the claim that "the scientist aims at finding a true description of the world"? The simultaneous denial of the second tenet while upholding the first is compatible for Popper. The key word is "aim": the scientist aims at discovering true descriptions but any conjecture can not be proved true or infallible. The scientist's aim is truth but the results lack certainty. Therefore, both Popper and instrumentalists reject essentialism since "essential and true" knowledge cannot be guaranteed.

Instrumentalists also deny that scientific theories aim at true descriptions. Agreeing with Popper that true knowledge eludes science, instrumentalists have retreated to a more "modest" stance. That is, since scientific truth cannot be ascertained, instrumentalists entirely avoid the concept and instead emphasize the practical efficacy of scientific knowledge. More precisely, scientific laws are not seen as an attempt to describe nature truthfully but rather are judged by their instrumental value: if a law functions coherently in the system, allows

accurate predictions, removes some of the existing problems, and encourages discoveries, then the law is used until a more effective tool is created. In short, instrumentalists believe that scientists aim only at empirical adequacy.

Instrumentalists avoid ontological claims and simply regard physical laws as human inventions and tools. The tool's function is not to mirror nature and "give truth," but simply to operate and predict well. Scientists disregard their tools when more proficient instruments are constructed. Popper stated that:

> . . . instrumentalism can be formulated as the thesis that scientific theories--the theories of the so-called "pure" sciences--are nothing but computation rules (or inference rules); [they are] of the same character, fundamentally, as the computation rules of the so-called "applied" sciences.[8]

Instrumentalism then has been highly compatible (though not synonymous) with the positivism of modern physics. For my purposes, positivism signifies an emphasis upon observation to verify any empirical statement or claim while subsequently rejecting attributing independent reality to any unmeasured or unobserved phenomenon. Positivism requires the precise empirical specifications of the conditions and constraints for any statement and hypothesis.

Instrumentalism and positivism have unproblematically co-existed in the orthodox interpretation of modern physics. (Philosophical) physicists generally do not believe that atomic theory describes the truths or essences of nature, but rather "nature as observed, measured and disturbed." Physicists investigate nature as changed and disturbed by the probing apparatus. Since observation can alter the atomic domain, nature <u>an sich</u> remains unknown. Thus, instrumentalism was an

attractive position to contemporary physicists since there has been the rejection of realistic claims that the theories's laws and entities actually refer to real and true entities. Yet, instrumentalist still believe that the resulting formalism is a powerful calculative instrument.

Popper concluded, after he published The Logic of Scientific Discovery, that science's tremendous power of explanation and prediction, in contrast to other forms of knowledge, stems from its realistic approach and interpretation. Science apparently has surpassed mere rule-formulation and puzzle solving since its theories directly "clash with the world." Good theories are not simply rules, predictions and abstract ideas. Scientific theories are viable if they conform to physical phenomena that are independent of human creation and concept. Popper argued that:

> Theories are our own inventions and our own ideas; they are not forced upon us, but are our self-made instruments of thought. This has been clearly seen by the idealist. But some of the theories of ours can clash with reality; and when they do, we know that there is a reality; that there is something to remind us of the fact that our ideas may be mistaken. And this is why the realist is right.[9]

For Popper, the modern scientific revolution transformed the world because of its realistic involvement with an independent, nonhuman world.

Popper argued that instrumentalists have not distinguished between "pure" theories (e.g., Newton's Laws) and technological computation rules. That is, highly abstract, "intangible" laws (e.g., Newton's Third Law concerning "action and reaction") have not been distinguished from calculative techniques (e.g., navigation rules). Instrumentalists

made them equivalent since all theories are mere calculative, useful constructs. But for Popper, pure theories are tested differently from calculative techniques.

> Theories are tested by attempts to refute them . . ., while there is nothing strictly corresponding to this in the case of technical rules of computation or calculation.[10]

Also, Popper argued that instrumentalism fails to properly account for falsification, the essential characteristic of rigorous science. The testing of an instrument is not synonymous with the conceptual falsification of a theory. Popper argued that:

> An instrument may break down, to be sure, or it may become outmoded. But it hardly makes sense to say that we submit an instrument to the severest tests we can design in order to reject it if it does not stand up to them; every air frame, for example, can be "tested to destruction," but this severe test is undertaken not in order to reject every frame when it is destroyed but to obtain information about the frame (i.e., to test a theory about it), so that it may be used within the limits of its applicability (or safety).[11]

Also, instruments continue to be used after "refutation"; the geocentric model of the planets is still used for teaching navigation. However, when a pure theory is refuted, theoretical science requires a better theory.

Finally, instrumentalism, for Popper, cannot account for the growth of scientific knowledge. The replacement of one tool by another does not adequately explain scientific progress. The growth of scientific knowledge implies more than instrumental development; rather, scientific progress implies that the world is more truthfully and realistically understood. Instrumentalism does not adequately explain the transcendence of the status quo. The new radical concepts of a scientific revolution cannot be based on mere instrumentalist criteria.

Science would simply remain within the theoretical domain of existing theories.

Similarly, instrumentalism cannot adequately explain the prediction of radically new events. Technology concerns the prediction and manipulation of "events of a kind which are known, such as eclipses and thunderstorms."[12] Theoretical science, on the other hand, predicts events of a new order and possibility "as the prediction which led to the discovery of wireless waves, or of zero-point energy, or to the artificial building up of new elements not previously found in nature."[13] The discovery of new elements then is usually a conceptual discovery and not a technical discovery, as commonly thought.

Popper argued that critical realism more appropriately explains discovery and prediction. Scientists attempt to explain to the world and actually interact with it. Scientific hypotheses clash with the world. The world, not the instrument, is the true source of refutation and contradiction. Scientists seek the true laws of nature and not simply better tools.

Popper used the heliocentric-geocentric confrontation to illustrate his argument against instrumentalism. The proponents of the geocentric system agreed that the Copernican theory was instrumentally advantageous. Many calculations and predictions were simpler and more accurate. The debate, however, concerned the truth of the Copernican position: despite the instrumental advantages, was it true? Since some Copernicans held the view as true, a confrontation ensued that eventually led to the demise of the Ptolemaic theory. This vigorous confrontation would not have occurred, Popper argued, if the debate

merely concerned the instrumental superiority of the successor. The debate over truth engendered scientific progress; without the issue of realistic description, the fight reduces to "which theory predicts more effectively?" "Truth" created an impetus for clarification, experimentation, refutation, and progress. Truth signifed, for Popper, the actual correspondence of statements with the "world of facts" or physical reality. Scientific progress requires the realistic confrontation of theories that attempt to better explain natural phenomena. Argumentation, the basis of philosophy and science, only matters when truth is at stake.

Although an analysis of Popper's views will be attempted later, one comment now on instrumentalism in contemporary science is relevant. Paul Feyerabend, in "Realism and Instrumentalism,"[14] supported Popper's argument for realism but significantly qualified it. Feyerabend (in his earlier works) agreed with Popper that instrumentalism in quantum mechanics was problematic and had created some conceptual impasses. Nevertheless, Feyerabend argued that Popper's views were also problematic since Popper rejected the instrumentalism of quantum mechanics on essentially a priori grounds and that he ignored the empirical reasons that encouraged instrumentalism. The positivism and instrumentalism of the Copenhagen Interpretation was motivated by physical, empirical discoveries and postulates such as the Projection Postulate and the disturbance principle, and not by a priori philosophical attitudes.

Feyerabend argued that it was a coherent and reasonable response when physicists interpreted their postulates nonrealistically. For

example, the novel particle-wave duality led physicists to consider this bizarre notion merely as a conceptual instrument rather than a realistic portrayal of the microdomain. Some scientists (such as Bohr and Heisenberg) thought that the quantum paradoxes (such as referring to a particle simultaneously as a wave) were the result of human, scientific limitations, rather than realistic truths of an noncommonsensical natural order. Also, Schroedinger's equation and the subsequent wave mechanics described waves in an abstract, mathematical space and not in real, physical space. Thus, the formalism and the peculiarities contained in quantum mechanics "naturally" encouraged physicists to view the new theory instrumentally; it was suitable for very accurate predictions but probably inadequate to explain the atomic domain "as it truly is." Feyerabend concluded that "any attempt to give a realistic account of the behavior of the elementary particle is bound to be inconsistent with some very highly confirmed laws."[15]

If scientists were always constrained to interpret their results and theories realistically, they would be forced to say, for example, that an electron truly is a nonlocalized wave and a localized particle. In the conventional understanding (but possibly classical treatement) of the Principle of Complementarity, some consider this statement the equivalent of "a fundamental entity has both A and non-A attributes." Rather than encouraging such contradictions and paradoxes, Bohr circumvented the entire dilemma and stated that the quantum formalism should be considered as an instrument and not a set of realist truths. In fact, with his notion of quantum wholeness (or the unity of the object with its experimental conditions), Bohr cleverly side-stepped

this apparent contradiction. That is, an electron appears as a particle in certain arrangements and appears as a wave in different arrangements. (See Chapter Two.)

Feyerabend concluded that a rejection of an instrumentalist theory purely on quasi _a priori, realist_ grounds was shortsighted. A "forced marriage" between quantum theory and realism, after scientists have reasonably and "modestly" adopted instrumentalism, was philosophically and empirically insensitive. Feyerabend argued that the philosophical attitude of realism could be adopted only if the current physical theory was transformed and the instrumental aspects were changed. Thus, if quantum theory is transformed by a future theory and many of its paradoxes are removed, then realism perhaps could be embraced. Until then, realists must accept an instrumental theory or else formulate new premises and interpretations of realism. In short, Feyerabend's argument brought out an important paradox in Popper's philosophy of science that will play a large role in my assessment of his work. While Popper advocated a policy of bold conjectures and refutations, he held several philosophical premises and constraints that clashed with progressive science.

Scientific Realism and the Three World Schema

Popper's "Quantum Mechanics without 'The Observer'," is related to another article published the same year, "Epistemology without a Knowing Subject." Along with "On the Theory of the Objective Mind," these essays give a concise presentation of Popper's concern with nonrealism in physics and philosophy. Popper developed an elaborate epistemology

and an analysis of modern physics that would circumvent any positivistic reference to the subject or observer. Consequently, Popper thought that philosophical and scientific knowledge could be entirely objective and imitate the apex of objectivity, classical physics.

Popper distinguishes between two major categories of philosophers. There are belief philosophers and scientific (objective) philosophers. Popper calls Descartes, Locke, Berkeley, Hume, Kant and Russell belief philosophers. They ground knowledge within the knower's consciousness, rather than in the objective content of the known. Belief philosophers attempt to validate objective knowledge through individual mental states and perceptions. The subjective acts of thinking, perceiving and judging are the basis of truth and falsity. In essence, belief philosophers think that the foundation and justification of knowledge is found in the structure and activity of consciousness.

Popper rejects this emphasis upon the genetic source of knowledge. Belief philosophy stands opposed to scientific, objective epistemology since belief philosophy stresses the perceiver rather than the perceived. The objects of consciousness and knowledge are considered secondary and the emphasis remains upon the structure of consciousness, perceptions and experience in general. Thus, belief philosophy primarily concerns subjectivity. Objective knowledge, Popper argues, became problematic with this subjective orientation and foundation.

Objective philosophers (e.g., Bolzano and Frege) do not emphasize the perceiver's consciousness and experience of phenomena and objects. Instead, a scientific epistemology focuses upon the content of theories, problems and statements. Popper quotes Frege: "I understand a thought

not by the subjective act of thinking but by its objective content."[16] For example, a problem within geometry is not resolved by an analysis of subjective spatial experience but by analysis of various mathematical theories, similar problems in geometry, etc. Conscious processes and structures are not relevant to the solutions of objective problems. Theories and problems are justified by the consideration of empirical factors, the arguments of alternative theories and other factors external to the subject. A theory is not impugned by subjective experience and Popper argues that the emphasis upon consciousness and mental categories is in general incapable of solving objective problems. Popper listed three examples of subjective knowledge:

> (1) I know you are trying to provoke me, but I will not be provoked.
> (2) I know that Fermat's last theorem has not been proved, but I believe it will be proved one day.
> (3) From the entry "Knowledge" in The Oxford English Dictionary: knowledge is a "state of being aware or informed."[17]

Popper also gave three examples of objective knowledge:

> (1) From the entry "Knowledge" in The Oxford English Dictionary: knowledge is a "branch of learning; a science, an art."
> (2) "Taking account of the present state of metamathematical knowledge, it seems possible that Fermat's last theorem may be undecidable."
> (3) "I certify that this thesis is an original and significant contribution of knowledge."[18]

Belief philosophers stress "I think," "I perceive," "I believe." "Cogito, ergo sum" is the most famous attempt to legitimate knowledge through belief. Popper thought that to ground objective knowledge within the individual's experience made science into belief and failed to establish its objectivity. In the above examples, note that truth and falsity are not prerequisites for objective knowledge. For Popper,

objective simply means a description without reference to subjective structures or experiences.

From these premises, Popper developed his three-world schema. The first world is the natural, material world of objects and processes, both organic and inorganic. The second world is the subjective domain of mental states. This world includes feelings, beliefs, desires, fears, and in sum, human psychological experience. The first and second worlds parallel the traditional demarcation between mind and matter. Traditional epistemologies strove to unify or separate these realms, through dualism or monism. Popper, on the contrary, was a pluralist: he not only upheld the autonomomy of both realms but added another.

Popper's additional world, his third world, pertains to civilization and science. This world is the autonomous realm of language, knowledge and theories. Theoretical systems, problems, problem situations, arguments (both true and false) are all "objects" of Popper's third world. In a word, Popper called these objects "intelligibles, i.e., possible (or virtual) objects of our understanding."[19] This realm "possesses objects and properties" that transcend their creators and users. The third world is the domain of nonsubjective knowledge.

> Knowledge in this objective sense is totally independent of anybody's claim to know; it is also independent of anybody's belief, or disposition to assent; or to act. Knowledge in the objective sense is knowledge without a knower; it is knowledge without a knowing subject.[20]

How is the third world actually autonomous from its creators? Mathematics is Popper's primary example. While mathematics is a human construction, it assumes a "life of its own" after its creation. For

example, the number system has autonomous properties and problems. Mathematicians did not create the prime numbers per se; primes concomitantly arose with the invention of the general number system. Thus, the existence of prime numbers, or even and odd numbers, were not created by intention but were the unplanned by-products of the number system. Many mathematical properties are not constructions but rather are discoveries of latent properties within a particular system. Mathematicians create these systems, of course, but not the properties and problems that autonomously exist within the structure. (However, Popper does not sufficiently address forms of mathematics where decisions and "undecidability" play a key role.)

One of Popper's central points was that mathematical systems, and third world objects in general, are independent of subjectivity. Certain mathematical properties and problems may never be experienced in the second world. After a set of theorems is created by a mathematician, the theorems assume an autonomy from this mathematician and his/her unique, subjectivity. Many aspects of a theorem may never be considered or assessed within human cognition.

In what manner is a third world object dependent upon the second world? For example, is a book's content dependent upon the subjective experience of the reader? Popper's reply was noteworthy: the book is not only autonomous from its reader, it does not even require a human author. Popper used the example of a book of logarithm tables created by a computer and later never read. In this case, the book had no subjective author and also was never subjectively experienced. Although the contents of the book were never experienced as a mental state it

nevertheless remained a third world object. Popper concluded that the book was an autonomous epistemic object (and not simply a physical object) since it possesssed the potentiality of being known.

One conspicuous feature of the third world is its "immensity." The third world does not consist simply of philosophic and scientific theories and statements, but virtually all true and false statements about the world.

> . . . we can ascribe to the third world not only universal concepts or notions, . . . [but also] false propositions . . . and, in addition, all kinds of nonmathematical propositions or theories.[21]

While false and nonscientific statements exist in the third world, Popper argued that the most important "inmates" of this realm are scientific and philosophic problems and theories. This "bias" was justified since science is critical and refutes its theories, and thus remains progressive.

Popper's schema depicting the growth of science demonstrated the character and autonomy of third world objects.[22] This schema (in simplified form) is

$$\ldots P_i\text{--}TT_i\text{--}EE_i\text{--}P_{i+1}\text{--}TT_{i+1}\text{--}EE_{i+1} \ldots$$

The initial problem (P_i) confronting a scientist or philosopher leds to TT_i, the tentative theory or solution to the problem. The subsequent EE_i refers to error-elimination, or the attempt to purge the theory of inadequacies while P_{i+1} signifies new problems that inevitably arise with new theories and hypotheses. These new problems are not merely created by subjective considerations but by the theory's objective problem situation (e.g., empirical inconsistencies, logical incoherence, stronger alternative theories). Thus, one might say that "P_{i+1} are not

created by individuals but usually arise from objective evidence and inadequacies." New problems previously unseen arise from the problem situation per se.

> They emerge autonomously from the field of new relationships which we cannot help bringing into existence with every action, however little we intend to do so.[23]

As stated, both true and false statements exist in the third world. The proposed theory TT is, naturally, a fallible hypothesis. Thus, EE then will not be complete and the initial problem will not be fully answered. An example is a set of problems (P_i) that plagued the geocentric view (e.g., the orbits and epicycles of the planets). After the proposal of the Copernican system (TT_i), many problems concerning the orbits of the planets were removed; the cumbersome epicycles were transformed or removed. Through Newton's error-elimination, many of the problems of the new system were corrected. (Newton's use of Kepler's Laws, along with his law of gravitation, nicely organized the Copernican system.) Nevertheless, the achievements of Newton were not perfect, and new problems (P_{i+1}) with planetary motion later emerged; for example, the perihelion of Mercury could not be explained by the Newtonian formalism. A new tentative theory (TT_{i+1}), namely, Einstein's general theory of relativity later explained this problem. New problems and inadequacies will undoubtably plague the general theory of relativity and the cycle of conjecture and refutation will elicit better theories.

Popper intended to show that the growth of knowledge and the development of third world objects essentially involves external, autonomous theories and problems. If science and philosophy attempts to ground knowledge upon the thought processes of scientists, then

scientific progress will be impaired. The emphasis upon the subject or the observer, rather than the object and the observed, blocks both science and philosophy.

Imre Lakatos agreed with Popper that epistemic objects developed through this autonomous, yet perpetually critical cycle. While mathematics is often considered to be an a priori, deductive science, Lakatos argued that mathematics also develops in this cycle of conjecture of a tentative theorem and its subsequent refutation by the problems it autonomatically creates as a by-product. Mathematics actually parallels the growth of empirical theories, struggling against incomplete hypotheses, theorems and errors.

> [Mathematics] does not grow through a monotonous increase of the number of indubitably established theorems but through the incessant improvement of guesses by speculation and criticism, by the logic of proofs and refutation.[24]

For Popper and Lakatos, the four-step schema of conjecture and refutation displays that no reference to the knower or observer is necessary. That is, one need only to refer to the problem situations of science to explain the critical growth of knowledge; any discussion of any subjective factors are superfluous. The third world then avoids any essential reference to the process of observation. It appears that this view motivated Popper's condemnation of the nonrealistic interpretation of modern physics.

After this discussion of the autonomy of the third world, I now turn to a brief analysis of the interrelationship of the three worlds. In Popper's view, the nonrealism issue in modern physics involved the interrelationship of the three worlds and threatened to blurr their distinctions and autonomy. Since the observer's choices and activities

(i.e., the second world) during measurement and observation was responsible (in the Copenhagen view) for the determination of first world objects, realism was suspended in modern physics. Many scientists and philosophers thought that unmeasured or nonobserved properties or objects as unreal and meaningless. For Popper, the "observer" then threatened the objective (third world) character of physics and even encroached upon subjectivism.

While Popper's three worlds are autonomous from each other, they obviously interact and are not "private monads." For example, Popper stated that the second world is the link between the first and third worlds. The natural world does not directly create any third world object nor do third world creations (e.g., an airplane design) spontaneously appear in the physical world. The second world creates (some of) the third world and then can create their (first world) physical existence. Yet, although third world objects such as mathematical theorems are the products of consciousness, they are independent of consciousness and assume a unique ontological nature. As discussed above, once the third world objects are created, previously unseen properties are discovered and the objects are independent of their particular creators or users. Popper stated,

> . . . my third world has no similarity whatever to human consciousness; and though its . . . inmates are products of human consciousness, they are totally different from conscious ideas or from thoughts in the subjective sense.[25]

Emphasizing this <u>simultaneous</u> human creation and yet ontologically autonomous object, Popper added that:

> . . . the third world originates as a product of human activity. One can even admit that the third world is man-

> made and, in a very clear sense, superhuman at the same time. It transcends its makers.[26]

While third world objects transcend their makers and also the first world, the third world obviously can have enormous effects upon the first world. The liaison between the first world and the third world is the human conscious realm, the second world. Popper said that:

> The first world and the third world cannot interact, save through the interaction of the second third, the world of subjective or personal experiences.[27]

Classical physics distinguished the natural world from the scientist's activities, choices and dispositions whereas in modern physics, there are empirical discoveries and principles that blurr the separability of first world objects from the effects, conditions and choices of the scientist. While quantum theory does not necessarily involve the observer's consciousness (though some propose that consciousness is a component of the "collapse of the wave packet"), the theory often requires the <u>physical</u> reference to the specific character of observation. Instead of the "naked, pure object," we now have in quantum theory a union between the object and its observation.

When proponents of the orthodox interpretation of quantum theory argued that the "objective and observerless" discussion of atomic objects was no longer possible, Popper thought that the necessary distinctions for objective science were being destroyed. He argued that a potent, nonsubjective science needed a three-world dichotomy in order to maintain the special ontological nature of scientific knowledge. Otherwise, as in belief philosophy, the object of knowledge is lost and is problematically blurred with the subject (or observer). Science

must rigorously maintain these distinctions or else risk a fate similar to belief philosophy.

Before describing Popper's specific critique of the suspension of classical realism in contemporary science, I will summarize in Chapter Two several important empirical principles and discoveries that led to positivistic Copenhagen Interpretation of quantum theory. This position was responsible for Popper's incessant vociferations about "the crisis in modern physics." As we will eventually conclude, the Copenhagen Interpretation posed questions and problems that realists such as Popper have been unable to resolve or refute.

Notes

[1] Karl Popper, Conjectures and Refutations (New York: Harper and Row, 1965) 37.

[2] J. Newton-Smith, The Rationality of Science (Boston: Routledge and Kegan Paul, 1981) 49.

[3] Popper primarily used modus tollens; Major premise: If Newton's theory is valid, then Mercury's orbit must be thus-and-so. Minor premise: The orbit is not as predicted. Deductive conclusion: Newton's theory is incorrect (with respect to Mercury's orbit).

[4] Karl Popper, op.cit., 37.

[5] Ibid., 51.

[6] Ibid., 103.

[7] Ibid., 103-4.

[8] Ibid., 111.

[9] Ibid., 117.

[10] Ibid., 112.

[11] Ibid., 112-3.

[12] Ibid., 117.

[13] Ibid., 117.

[14] Paul Feyerabend, "Realism and Instrumentalism," The Critical Approach to Science and Philosophy, ed. Mario Bunge (Glencoe: The Free Press, 1964) 280-308.

[15] Ibid., 301.

[16] Frege, quoted by Karl Popper in Objective Knowledge (Oxford: Oxford University Press, 1979) 109

[17] Karl Popper, Objective Knowledge, 110.

[18] Ibid., 110

[19] Ibid., 166.

[20] Ibid., 109.

[21] Ibid., 156.

[22] Ibid., 138.

[23] Ibid., 119.

[24] Imre Lakatos, Proofs and Refutations (Cambridge: Cambridge University Press, 1976) 5.

[25] Karl Popper, Objective Knowledge, 126.

[26] Ibid., 159.

[27] Ibid., 155.

CHAPTER TWO

THE EMPIRICAL CHALLENGE TO POPPER'S REALISM: QUANTUM THEORY AND ITS ORTHODOX INTERPRETATION

In this chapter, I will describe the general physical theory and its principal interpretation that challenged realist philosophers such as Karl Popper. This challenge to the classical conceptual premises of science apparently concerned Popper more than a parallel challenge by logical positivism to modern philosophy. Indeed, Popper claimed that the new nonrealist attitude by modern scientists signified a "crisis" within both science and society.

Several key facets of Popper's realism become more transparent in his argument against the predominant nonrealist interpretation of modern physics, the Copenhagen Interpretation. Several important constraints within Popper's notion of realism that are absent in his general philosophical essays are explicit in his attack upon the Copenhagen Interpretation. Consequently, the evaluation of Popper's realism can be more thorough with this important "empirical" dimension.

Accordingly, I now describe several components of classical physics and quantum theory that pertain to classical realism. The brief characterization of classical physics is necessary in order to provide a contrasting framework for modern physics and its conceptual transformation. The discussion of classical physics is also important since Popper's criticism of the Copenhagen Interpretation was largely

motivated by constraints from classical physics. I will then discuss in greater detail the conceptually controversial Copenhagen Interpretation. This view of physics was the impetus of much of Popper's writings on modern science.

In this part of the dissertation, the notion of the "the observer" will be pivotal in the analysis. Popper thought that the subsequent nonrealism in modern physics arose from the misunderstanding of the role and effect of measurement and observation in atomic physics. Thus, Popper sought to undercut the contemporary understanding of the problem to reaffirm realism of classical physics. The incessant discussion of "the observer" then signifies the "source of controversy" and Popper's subsequent attempt to dismantle it.

The Character of Classical Physics

Classical physics has been an impressive and comprehensive system. The system has great predictive power, simple clarity of foundational principles (e.g., Newton's Laws) and broad applicability. Classical physics was so effective and successful that many scientists actually envisaged its eventual completion (i.e., encompassing all significant phenomena). With the unification of Maxwell's work in electromagnetism along with Newton's Laws in mechanics, most known physical phenomena received unified explanations from basic principles. Hudson and Nelson, summarizing this "grand unification," stated,

> Toward the end of the 19th century, our understanding of what is now called classical physics had reached an impressive stage. It was believed that almost everything was known about the physical world and its interactions--at least, this was the opinion expressed by several well-known scientists at that time. A more embarrassing misconception can hardly be

> imagined. Yet, considering the widespread success of Newtonian mechanics in explaining the motion of all kinds of objects from baseballs to the solar system, and the fact these same ideas also brought all heat phenomena under the rules of mechanics, it seemed reasonable that we had, at last, found a great unifying theory that explained all phenomena. There were also radio waves, light, and so forth, which were obviously apart from mechanics, but these, too, were brought together in another unifying theory, that of Maxwell's electromagnetism. Together these two theories seemed to complete our understanding of all natural phenomena in terms of particles and waves.[1]

However. in 1895 and in the decades to follow, the solid foundations of classical physics eroded. Rather than the grand unification of physical science, physics was transformed and a new view arose. But before analyzing this new view, it is important to briefly discuss the classical view.

In classical physics, objects have definite, precisely specifiable structures. Complex objects are comprised of components that can be described by the fundamental laws of basic elements. That is, macroscopic objects can be accounted for in terms of elementary particles which possess definite spatiotemporal locations. For a particle, exact ("nondispersive") spatial coordinates can be assigned at any time; definite, sharp descriptions of its motion, or trajectory, are possible in most kinematic situations (with the principle exception involving high numbers of particles). Of course, not all physical phenomena are comprised of particles. Sound, for example, assumes the physical form of waves. Waves are not sharply localized in space but rather spread out over a finite region of space. The motion and behavior of waves is, however, completely predictable in classical mechanics. In short, there is no limit, in principle, to the precision that the properties of a physical system can be measured.

Success in exact prediction encouraged a belief in causal determinism. The laws of classical mechanics allowed an exact description of the future state of a system if the initial conditions were known. That is, precise and predictable consequences followed from known antecedent conditions.

> The temporal sequence of states of any system S is such that every instantaneous state of S is causally or functionally generable from the immediately, temporially preceding state of S and its physical environment.[2]

For example, due to a thorough subsumption of the causal, temporal sequence of solar and lunar motion within classical law, exact descriptions of eclipses can be determined hundreds of years in advance. Classical physicists took a metaphysical view of deterministic causality. The scientist-mathematician Simon Laplace thought that eventually all phenomena would be unified in a deterministic system. He felt that if the present state of nature could be known thoroughly, all future states could be exactly predicted. Laplace claimed,

> We ought then to regard the present state of the universe as the effect of its previous state and as the cause of the one which is to follow. Given for one instant a mind which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it--a mind sufficiently vast to submit these data to analysis--it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes.[3]

Thermodynamics in the 19th century slightly weakened the quest for a completed deterministic physics. The study of heat revealed that billions of atoms were involved in many physical states and that precise knowledge of an individual particle within such an ensemble was impossible. On the other hand, the overall tendencies of these

ensembles could be ascertained with great accuracy through statistical mechanics. In this way, deterministic prediction was salvaged even when the possibility of determining specific particle-interaction was limited. Thus, the treatment of large numbers of particles remained deterministic, and statistical mechanics did not change the metaphysics of physics. As Hooker summarized,

> Statistical theories represent the average behavior of physical magnitudes for a large number of distinct physical systems identical in other relevant respects but whose precise particular magnitudes for the quantities in question are distributed randomly. Each of the elements of such a statistical ensemble is, however, definitely characterizable in all relevant respects. Thus, statistical theories represent less than complete knowledge of the state and behavior of the ensemble.[4] (emphasis added)

Another consequence of the success of classical physics was the belief that precise scientific knowledge mirrored nature. Encouraged by exceedingly accurate predictions and thorough descriptions, a realistic and truthful account of nature appeared possible. Most anomalies were eventually explained by classical mechanics and many scientists optimistically envisaged the (theoretical) completion of classical mechanics. The system appeared complete in the description of all "significant" phenomena (e.g., kinematics, gravity, thermodynamics, and electromagnetics).

As classical physics described nature in spectacular, astonishing levels of precision, most physicists interpreted this success realistically. That is, they believed that classical laws captured (beyond the limitations of culture or subjectivity) physical reality. Most scientists dismissed any view that these laws were mere instrumental calculation devices.

Accordingly, the concept and theory of measurement and observation were unproblematic and, as Putnam remarked, played no essential role in the physical theory.[5] Measurement in classical physics was viewed as a straight-forward, fully accountable interaction between the measuring apparatus and the physical system under observation. The scientist's actions and disturbances within this interaction with the observed phenomena could be controlled and calculated for a relatively disturbance-free result. In fact, the effects of the observer in classical mechanics were controlled to the extent that measurement was considered "observer-free." Paul Davies stated,

> First, . . . although the measurement or observer will necessarily involve a disturbance to the subject of scrutiny, this disturbance can be accurately computed and allowed for when deducing the result. Thus, the measurement of a liquid's temperature can be corrected by knowing the thermal properties of the thermometer and its initial temperature. In a world where every atomic motion is rigorously determined by mathematical laws one can, in principle at least, take account of even the minutest disturbance from the measurement process. Second, by sufficient ingenuity and technical skill it is possible, according to Newtonian theory, to reduce the troublesome disturbance to an arbitrarily small amount. Newtonian mechanics provides no limit to how weakly two systems may interact.[6]

Since the disturbance during observation was negligible, many physicists believed that the properties of physical systems obviously existed independently of observation. The specific condition of physical states was not essentially dependent upon observation. Measurement did not uncontrollably induce effects that altered the observed object(s); in the exceptional cases, scientists could eventually correct and account for any disturbance, and tend toward an "objective" result. Thus, with this unproblematic character of

measurement and observation, the classical acceptance of realism was not surprising.

An interesting aspect of classical physics' "observer-free" physical description and its deterministic laws was the notion of "prediction without measurement." In simplified and more-idealized conditions, scientists could precisely predict and describe the behavior of physical systems without direct measurement. That is, if the "initial conditions" were known, then any later state of the system could be known without any subsequent observation. Thus, the appearances of comets or eclipses could be precisely predicted and antecedently known in advance. Or, on a smaller scale, the motion of a pendulum could be antecedently known if the initial displacement, velocity, air resistence and friction are determined. Paul Davies claimed that:

> . . . [in classical physics,] it was no longer necessary to observe the world to ascertain how it would behave: you could also compute it with a pencil and paper. Using mathematics to model the laws, a scientist could predict the future behavior of the world, and retrodict how it behaved in the remote past.[7]

This "knowledge without measurement and observation" further encouraged the classical belief of an (observationally) independent physical reality. Since many phenomena could be known and described without any subsequent measurement, the physical world seemed autonomous from observation. When measurements were necessary, (usually) no uncontrollable effects inundated the phenomena. Consequently, the notion of an "observation-dependent" world remained foreign to classical physics.

By the end of the 19th century, classical physics had matured into a coherent and powerfully accurate system. Although the theory possessed some anomalies, most physicists were confident that any problems could be resolved and "digested." While the synthesis of classical mechanics, thermodynamics and electromagnetism was not perfect, few scientists envisaged that a several "peripheral" anomalies would lead to the entire transformation of this amazingly successful theory. Yet, amidst the hope for a grand unified system, the foundation of classical physics was transfigured and displaced.

The Rise of Quantum Theory

Many concepts and discoveries in quantum mechanics were not only foreign to classical mechanics but often contradicted fundamental, "unassailable" views. The "commonsense" notions of classical physics were as severely challenged by quantum mechanics as Aristotle's "common sense" was challenged by Galilean mechanics. The shift in foundations from classical physics to quantum physics transformed not only the previous conceptual premises but also the mathematical, physical and technical fundamentals. The entire conceptual structure of classical physics suddenly appeared problematic. Steven Toulmin remarked that "every 19th century axiom turned into a 20th problem."[8]

What exactly was the quantum mechanical revolution? How did the commonly accepted notions of a continuous, determinate and "observer-free" world give way to a nondeterministic, discontinuous, and observer-dependent view? I cannot give here an exhaustive description of quantum theory's development. Unfortunately, the following exposition includes

only those elements of modern physics that are relevant to my discussion of Popper.

The year 1900 is often cited as the birth of quantum theory, although discoveries and experiments beginning at least five years earlier were important. Max Planck's theoretical analysis of black-body radiation initiated the first major breakthrough. His findings revealed that energy states did not form a continuous distribution as traditionally believed but instead existed only in discrete values. Pictorially, one could say that energy ascends (or descends) on a stair case, appearing from step to step but not between steps. In macroscopic (classical) conditions energy exhibits no breaks or discontinuities. Thus, classically, energy "flowed like water waves" with continuous movement. On the other hand, quantum theory revealed that _microscopic_ phenomena (often) possess discrete energy quanta. The term "quantum" came to signify the discrete and acceptable levels of energy. Classical physics had overlooked the discrete quantum levels because the quantization of energy states is unnoticeable for macroscopic systems. The focus of classical physics remained upon the overall macroscopic tendency of the system; it did not perceive the microscopic quantum effects.

Soon quantum effects were noticed in microphysics beyond Planck's work. While discontinuity was a radical concept only grudingly accepted within a limited domain, Einstein carried it much further. As Toulmin remarked,

> At first, Planck's device [i.e., hypothesis] appeared as an effective but arbitrary fudge. Physicists continued to think of electromagnetic waves as spread smoothly through space, but supposed that--for some unexplained reason--_interactions_

> between matter and radiation were discontinuous. But in 1905, Albert Einstein kicked open the theoretical door which Planck had unlocked and walked right through. Radiation, he argued, was not only exchanged in discontinuous packets: it actually existed in discontinuous packets. Certainly these energy packets consisted of electromagnetic radiation, having a definite frequency, but the waves always travelled in bundles or "photons." So a beam of light comprised not a smooth flood of electromagnetic energy but a rain of separate wave packets, each with its own individual quantum of energy and momentum. Photons were, in effect, a kind of particle; each of which would strike against a surface with a definite impact.[9]

At this point, several established physical concepts became problematic. The two primary descriptions of phenomena, particles and waves, were significantly transformed. The optics of classical physics had clearly determined that light and all electromagnetic radiation were wavelike. Einstein complicated matters by equating light with particles (viz., photons) without denying its wavelike features. He had conjectured that several existing problems could be clarified by using discrete levels of particle-groups. Louis de Broglie then postulated that the wave-particle duality applied not only to radiation but to particles of matter. De Broglie's proposal complemented Einstein's view of photons. Einstein saw waves as particles and de Broglie conversely proposed that mass also possessed a wavelength. Though the particle-wave duality was initially a tenuous conjecture, the experiments by Davidson and Germer eventually substantiated de Broglie's proposal. They found that electrons (particles) created diffraction patterns, which are characteristic of wave phenomena. Additional experiments revealed that other particles under similar conditions exhibited wavelike properties.

Concurrently in the macroscopic domain, new developments unleashed a further onslaught upon the tradition. Einstein's General Theory of Relativity treated Newtonian Mechanics as a "special or limiting case" (i.e., effective only under certain conditions). Consequently, despite the hope in the late nineteenth century that classical physics would be complete, it had become instead a subset of quantum theory and the theory of relativity.

These developments were disconcerting since classical physics had produced unambiguous and accurate results with distinct wave and particle descriptions. (Classical) waves and particles had possessed definite and distinguishable characteristics; for example, particles were localized and waves were nonlocalized. Maxwell's unification of electromagnetic (wave) phenomena was highly successful; likewise, particle descriptions posed few problems in kinematics and thermodynamics. However, with the rise of modern atomic theory, these opposing descriptions were paradoxically united.

Niels Bohr epitomized the revolutionary aspect of the quantum mechanics' particle-wave duality with his famous Principle of Complementarity. "In the quantum domain, wave and particle aspects complement each other. Though the choice of one description precludes the simultaneous choice of the other, both are required for a complete understanding."[10] Under certain conditions, matter and light display particle characteristics while manifesting wave characteristics under other conditions. Yet, as the original formulation of Principle of Complementarity described, no experiment could ever amalgamate both and demonstrate a simultaneous wave and particle phenomena (although this

restriction is now considered as inaccurate). Bohr concluded that the unambiguous and distinguishable classical concepts were impaired at the microlevel.

After this displacement of the traditional particle-wave distinction, along with Planck's quantum hypothesis (i.e., discrete energy levels), the deluge against classical physics continued with the collapse of determinism. Although this issue is not directly related to my topic, two aspects of quantum indeterminism are relevant and will be used in the following discussions. First, at the atomic level, the precise determination and measurement of a particle is impossible. The Heisenberg Uncertainty relations prohibit the exact determination and knowledge of a particle's location or momentum. Second, atomic states often exist in an indeterminate condition. This indeterminacy, designated by the "Projection Postulate," involves the <u>simultaneous superposition of different states</u> of an atomic particle or system. Microscopically, upon observation or some interaction with a macroscopic apparatus, the superposition then collapses into one determinate state. Crudely put, this indeterminacy is not unlike a die (with its "superposition" of six states) before it settles on one side. If the die is an atomic particle with six different possible states, the measurement of the die-particle will change its indeterminate condition and "force" it into one determinate state. Physicists are convinced that (microscopic) nature is indeterministic but that it can assume only certain allowable quantum states ("<u>eigenstates</u>").

With this brief prelude, we can now approach the physical hypotheses and discoveries that have led to the new importance of

observation in quantum theory and the subsequent nonrealism. It appears that there are (at least) three primary aspects of quantum theory that undercut the traditionally "observerless" physics. These three aspects are (i) the problem of measurement and disturbance of atomic phenomena, (ii) the Projection Postulate and the physical determination of eigenstates by the act of measurement, and (iii) the EPR results, which dramatically supported the Copenhagen Interpretation's unification of the observation to the observed phenomena. The EPR tests will not be described here since they will be discussed and utilized at length in the next chapters.

As we saw, measurement in classical, macroscopic physics was a controllable interaction. As Paul Davies stated above, the influence of the measuring apparatus was known and calculable. But on the atomic level, measurement and the physical interaction between the observed object and the observing tools was not an "innocuous act."

> Atoms are so delicate that [the observing and measuring] forces which are, by everyday standards, incredibly minute, can nevertheless produce drastic disturbances. The problem of carrying out any sort of measurement on an object only 10 billionth of a centimeter in size and weighing a millionth part of a billion-billionth of a gram, without destroying, let alone upsetting it, are formidable.[11]

Whereas the macroscopic world has remained unperturbed by the act of observation, fundamental particles are inundated by these forces.

This "disturbance during measurement" problem in atomic physics originates from a physically simple fact: the observation of a particle requires some light (or, better, electromagnetic radiation) which reflects off the particle and into a sensor. However, the particles are exceedingly minute and are disturbed by the probing signal. The energy

of the incident signal alters the particle's position or velocity (depending upon the energy of the signal). This disturbance of the particle is not a technical deficiency that could be circumvented by more efficient means. A minimum amount of energy is necessary to detect and interact with particles. This energy will necessarily modify the original state of the observed phenomena. As N.R. Hanson claimed, "To learn about a particle, we must interact with it,"[12] and this interaction unavoidably requires an energy exchange that alters the observed.

The perturbation and (occasional) destruction of particles does not undermine knowledge about the particles. Physicists are forced to use many similar particles (prepared in similar states) and to find the statistical behavior of the large ensemble. Thus, while certain characteristics of the ensemble are understood, information about individual particles is virtually impossible (due to the energy-exchange problem). A current quantum mechanics text describes the process as follows:

> . . . quantum systems are typically so small that the process of observing them alters them. Since only one observation can be carried out on each system, the only way to study them is to employ a continuous production line on which systems . . . are prepared in a manner which is identical as far as we can tell. These "identical" systems are then subjected to various observations in which they are unavoidably altered or destroyed. Comparison of the results of different observations can then be used to describe the systems so produced. . . . [Thus] statements as to what will happen to a particular photon are meaningless.[13]

The "disturbance during measurement" problem then does not limit all information about particles but places restrictions upon measurement and the subsequent knowledge derived.

A parallel measurement problem in quantum theory is the Projection Postulate. As briefly mentioned in the discusssion of quantum theory's indeterminacy, the Projection Postulate involves a simultaneous superposition of different states. An atomic particle is considered to be in several states at one time until an observation or some other interaction with a macroscopic device. The particle is in an indeterminate superposition of eigenstates. Upon measurement of energy, the indeterminate superposition ceases and the particle is forced into one of its possible eigenstates. Thus, the act of measurement is often responsible for the cessation of the indeterminate state and the assumption of a unique "special or proper" state. Thus, "the state of the system will change from [the indeterminant state vector] psi to [an eigenstate] omega as a result of the measurement."[14]

While the coherent superposition of states does not occur in macroscopic, everyday experience, and thus is an odd and counterintuitive idea, it nonetheless plays a large role in the description and explanation of atomic states. This role subsequently indicates the new and important role of measurement of physics. Since measurement in classical physics did not (generally) change the observed state or condition (i.e., reduce a state vector into an eigenstate), measurement did not receive any special physical significance. Since, in quantum theory, "measurement throws a system discontinuously into a new state,"[15] as Putnam said, the act of observation is no longer considered (physically) negligible.

These physical developments motivated Einstein, Podolsky and Rosen (in 1935) to formulate a thought experiment circumventing the new role

of observation. Nevertheless, when the experiment was finally performed in the 1970's and early 1980's, the Copenhagen Interpretation of quantum theory and its emphasis upon the physical significance of observation was clearly supported and strengthened. In fact, the EPR tests probably have supported the observer-oriented interpretation of atomic physics more than any other conjecture or discovery. The subsequent philosophical implications of these physical developments have led to a careful scrutiny of the classical realist premise in physics and the philosophy of science.

A Brief Survey of the Interpretative Debate in Modern Physics

The creation of quantum theory caused a conceptual discontinuity with traditional classical physics. Quantum theory's peculiarities and paradoxes, in contrast to classical physics, engendered debates about the coherent interpretation of the new physics. The interpretation of quantum theory perhaps has been as challenging and problematic as any "purely" scientific problem of the theory.

With such empirical discoveries and postulates as the Projection Postulate, the Principle of Uncertainty and the "energy-exchange" relation, many scientists believed that the measurement (and subsequent knowledge) of fundamental entities was not simply of "nature itself" but more appropriately "the interaction between nature and scientist." The observed phenomena was influenced (in varying degrees) by the act of observation. Many physicists concluded that fundamental microphysics did not realistically describe nature itself but nature as disturbed, measured and observed by the apparatus and scientist. The concepts of

"nature itself," "unobserved nature," and "an independent physical reality" became problematic and even suspect.

Accordingly, the dominant interpretation of quantum theory suspended the traditional, physical realism through a form of positivism. This perspective in modern physics emerged independently of the logical positivism in modern philosophy. Werner Heisenberg, one of the central proponents of the new "anti-realism," rejected the tenets of logical positivism, yet he founded a positivistic interpretation of modern science completely upon concrete empirical considerations. For example, when he said, "if we want to describe what happens in an atomic event, we have to realize that the word "happens" can apply only to the observation, not to the state of affairs between two observations,"[16] Heisenberg's statement was motivated by the Principle of Uncertainty and not merely from positivist convictions. Since fundamental particles are perturbed during measurement and, more importantly, their values (for example, of location and momentum) are usually not known when they are not measured, Heisenberg thought that it was meaningless to discuss a particle independently of observation. Thus, physicists only describe atomic events but do not hypothesize metaphysical entities or forces.

Positivism also encouraged some scientists to abandon their former notions of objectivity. Heinz Pagels remarked that:

> . . . the Copenhagen Interpretation ended the classical idea of objectivity--the idea that the world has a definite state of existence independent of our observing it. . . . The atomic world does not exist in a definite state until we actually set up an apparatus and observe it.[17]

The classical language of describing the "object per se" was replaced by expressions such as "objects in certain experimental conditions." For

example, if one observes a set of interference patterns from an ensemble of electrons, the proper description would include the experimental conditions that produced this phenomena (such as a multi-slit apparatus); this account emphasizes the role of observation and the "creation of the phenomena" by the observer.

In addition to positivism, physicists often interpreted their theories and postulates instrumentally so as to avoid realist claims. Briefly stated, instrumentalism is the view that science is simply a set of statements and formalisms that describe and predict various phenomena without (necessarily) any real reference. Since the observed entities were partially the result of certain laboratory conditions and choices, the dominant interpretation of quantum theory did not hold that the formalism described "natural truth." Also, a realist and noninstrumentalist interpretation of the quantum mechanical formalism has been highly problematic. Thus, some scientists felt that an instrumentalist interpretation was a cautious and modest approach to the quantum theoretical complexities.

Instrumentalism arose primarily from empirical developments and not from *a priori* reasons. Popper agreed,

> How then did [instrumentalism] come about? As far as I can see, through the coincidence of 2 factors, (a) difficulties in the interpretation of the formalism of quantum theory, and (b) the spectatular practical success of [quantum theory's] application.[18]

Yet, as we will see in the next chapter, Popper thought that this instrumentalism, along with positivism, originated from a misinterpretation of the "core" formalism.

While most scientists adopted the Copenhagen Interpretation since it seemed to be the most logical, consistent and even "natural" extrapolation of the formalism, several key figures rejected this view. Although Einstein, Schroedinger and de Broglie played a large role in the formation of the original theory, they rejected Bohr's interpretation of the theory. They were convinced that the Copenhagen Interpretation represented a serious regression from the traditional and necessary premises of objectivity and realism. In fact, they felt the Copenhagen view abdicated the conventional goals of science.

On the other hand, some scientists, such as Vigier and Everett, interpreted the new active role of observation in far more extreme terms than the Copenhagen Interpretation. In fact, some of these views paralleled traditional subjectivism within modern philosophy. They felt that the observer's choices and awareness, along with his physical activities, were often fundamental in the measurement of atomic phenomena. Consider Richard Schlegel's statement:

> In quantum physics, the _observation process creates the event or property_ that is the individual datum of statistical description.[19]

Although Schlegel argued against traditional subjectivism, many physicists advocated subjectivism based upon this notion of the creation of phenomena. The activity of observation took a prominent role and the atomic world was considered indeterminate until the human observer interacted with it and forced it into an _eigenstate_.

Few physicists or philosophers have given serious consideration to the more extreme "subjectivist" interpretation of quantum theory (despite its adherence in popularized accounts of modern physics). Bohr

and Heisenberg cogently dispelled the subjectivist accounts by pointing out that the act of observation does not require a human, conscious observer; a programmed apparatus could completely perform the set of operations. In other words, the "collapse of the wave packet" and the discontinuous change of the indeterminate state vector into a quantum eigenstate occurs by the interaction with a macroscopic device, regardless of whether a human observer was present or not. Thus, Bohr and Heisenberg emphasized the physical process of observation and not the conscious observer. Likewise, when Schlegel mentioned the creation of atomic phenomena, he simply was describing the removal of an indeterminate state and the appearance of a concrete, determinate phenomena.

Although the extreme subjectivist account will not receive any more explicit discussion in the balance of the dissertation, this view is important when analysing Popper's critique of the Copenhagen Interpretation. Realists often equated the Copenhagen account with the extreme subjectivist account and would inaccurately attribute statements about the conscious observer to the Bohr position. (See his discussion of Walter Heitler and the Black-Box experiment in Chapter Three.) This confusion of the Copenhagen Interpretation with the (extreme) subjectivist position has probably played a major role in the lack of resolution of the philosophical discussions of quantum theory.

Nevertheless, even those more sensitive to the precise views of Bohr were dissatisfied with the orthodox interpretation of modern physics. While the orthodox view was not traditionallly subjective, they complained that it nonetheless was not objective. Realists argued

that the orthodox view still was dangerously close to the Berkelian esse est percipi, with the simple interchange of perception with observation. This view (purportedly) represented the loss of the physical referent since the "object per se" was replaced by the object-observation (or observed-observer) relationship.

Most realists argued that the traditional, classical use of the physical referent per se was the fundmental ground of objectivity. The new object-in-relation-to-observation may provide some instrumental and operational clarity but it signified a conceptual regression and a poor metaphysics. Mario Bunge stated,

> It is not just that observability is regarded as a criterion of reality, as a test of the hypothesis that something exists: the operationalist identifies reality with operational possibility or even (radical branch) with operational actuality, thereby denying independent reality to his desk or at least to its atomic constituents.[20]

Bunge thought that "the new physics reduced the physical object to little more than the grin of the Chesire cat. During this period, the observer displaced both matter and God."[21]

Popper agreed and thought that much more was at stake than a philosophical debate between realists and instrumentalists. As quantum mechanics matured by the 1930s, it succeeded at opening up significant avenues of investigation and explanation. But in addition, Popper worried that its "instrumentalist views" might prohibit further development within certain areas. For example, the Copenhagen Interpretation did not further develop the Principle of Complementarity since the particle-wave duality was an exceedingly useful explanatory device; ontological questions, such as "is it actually a particle or a wave?" were avoided. Yet, Popper thought that this instrumentalist

avoidance signified an impasse to scientific development since the "quantum paradoxes" should be further developed, falsified and replaced by less paradoxical postulates. Thus, instrumentalism was not only a philosophical shortcoming but also represented an impasse to the development of ("purely") scientific theories.

Popper approached the problems and complexities of modern physics from two interrelated domains. First, he attacked the orthodox understanding of quantum theory from a philosophical standpoint which attacked positivism and instrumentalism by an objectivist and classical realist philosophy that tried to dissolve the preeminence of the subject in modern philosophy. Second, he also challenged these views from a specific philosophy of physics which advocated a "quantum mechanics without the observer." From these two domains, Popper strove to reestablish the objectivity and realism of classical science. But before discussing his detailed attack upon the Copenhagen Interpretation, a thorough description of this view is now necessary.

A "Revolutionary" View of Physical Knowledge

The Copenhagen Interpretation was Popper's chief antagonist in modern science. His primary concern was the suspension of classical realism. He was convinced that the Copenhagen Interpretation or "orthodox" view of quantum theory would inhibit scientific development while also encouraging "irrational" conceptual ideas. In short, Popper thought the positivism and instrumentalism of modern science represented a "serious crisis" and that science would lose its progressive character.

In the first part of this chapter, we saw quantum theory's empirical postulates and discoveries that transformed classical physics. In the remainder of this chapter, I will elaborate upon the orthodox interpretation of this transformation since it was entirely responsible for Popper's attack upon the new nonrealism. This discussion will be restricted, of course, to the philosophical ideas of the Copenhagen Interpretation. However, a problem arises when discussing the Copenhagen Interpretation since it is not a unified interpretation. The views of the central members of the orthdoxy were often contradictory and thus no simple, unified view existed. Feyerabend remarked that ". . . the "Copenhagen point of view" . . . is not a single idea but a mixed bag of interesting conjectures, dogmatic declarations, and philosophical absurdities."[22]

Although Feyerabend and many others were not completely supportive of the Copenhagen Interpretation, it nevertheless has withstood serious criticisms and has proven to be a powerful new understanding of physics. With the recent testing of the EPR paradox that attempted to undermine the Copenhagen Interpretation, this view has gained further recognition and support. The EPR paradox was the most direct attack upon the orthodox view. Nevertheless, after the test results upheld this position, Niels Bohr's original interpretation and analysis of modern physics has been viewed as a significant and profound achievement.

Niels Bohr believed that quantum physics broke with the fundamental premises and beliefs of both modern science and philosophy. For example, he thought that the theory (i) subverted the classical notions of causality and determinism, (ii) questioned the restrictive

classical bimodal logic and dichotomies, (iii) rejected the exclusive use of continuous natural processes in classical physics, (iv) inhibited the traditional notion of physical substances possessing intrinsic, autonomous properties, and (v) transformed the relation of the observed system to the observing system, i.e., the physical act of observation assumed a new importance. In essence, Bohr thought that quantum theory transformed modern concepts as profoundly as any other theory in science or philosophy since the Renaissance. Unfortunately, most of the novel character of quantum theory must be ignored here since my thesis only concerns the clash with Popper's commonsense and classical realism.

The following discussion will be restricted to the two central figures of the Copenhagen Interpretation. Their analyses and articulations of atomic physics were largely responsible for the specific orthodox views, and other members usually either adopted these views without revision or else represented minor deviations. I will begin with Werner Heisenberg since his views were the most basic, straightforward account of the Copenhagen Interpretation. A discussion of Niels Bohr will follow since his position is more "advanced" and complex than the views of Heisenberg.

Heisenberg and the End of Classical Objectivity and Realism

The impetus behind Popper's struggle with the Copenhagen Inpterpretation can be epitomized in a few sentences from Heisenberg:

> It is true that quantum theory is only a small sector of atomic physics and atomic physics again is only a small sector of modern science. Still it is in quantum theory that the most fundamental changes with respect to the concept of reality have taken place, and in quantum theory, in its final

> form, the new ideas of atomic physics are concentrated and crystallized.[23]

Popper argued that this collapse of realism in modern physics was responsible for its instrumentalism and "irrationalist elements" such as the Principle of Complementarity, (the interpretation of) the Uncertainty Principle and the "collapse of the wave packet."

Heisenberg believed, on the contrary, that the abandonment of classical objectivity and realism was a valuable advance. As Einstein had overturned such Newtonian premises as absolute space and time, quantum theory penetrated even more deeply to the tacit and uncritical premises of classical science. One important premise was (classical) realism. As explained above, classical physics encouraged the belief that objects were physically independent of observation, and that science investigated this independent reality. Heisenberg stated,

> One was led to the tacit assumption that there existed an objective course of events in space and time, independent of observation; further, that space and time were categories independent of each other, and thus represented an objective reality, which was the same to all men.[24]

Although Ernest Mach had conceptually questioned classical realism and advocated positivism in the 19th century, most scientists had little empirical impetus to abandon realism until quantum theory. This theory proved to be an amazingly powerful and successful creation, and it rivaled classical physics.

> Thus we are perhaps justified in believing that we have reached a level of research comparable to that of the knowledge of the mechanics of the heavens after Newton. We may say that we are capable of a quantitative "calculus" of the properties of matter in all cases where mathematical complications do not prevent the execution of this task in practice.[25]

Yet, with the tremendous success of atomic theory, the conceptual foundations of science were tranformed. Heisenberg continued,

> A heavy price had, however, to be paid for the achievement of this ambition. It meant, in the simplest form, the loss of just that 19th century scientific conception of nature or, expressed more accurately, the loss of that conception of reality on which Newtonian mechanics rested.[26]

This deterioration of classical realism originated primarily from the new role of observation or measurement in atomic physics, although there were other sources (see the next chapter). As we have seen, the principle empirical conflict came from, in broadest terms, the physical effect of the interaction between the observed system and the conditions of observation.

> Nature . . . forces us to create some external disturbance in the course of each observation and thus withdrawing from our grasp an apprehensible picture of the atom. An atom can no longer, without reservation, be "objectively" described as an object in space changing in time in a definable manner.[27]

The measurement "problem" in quantum mechanics involved more than the "disturbance during measurement" relation and the "collapse of the wave packet" (or, as von Neumann designated, the "Projection Postulate"). Due to the Uncertainty Principle, the exact location of atomic objects usually could not be exactly determined without observation. That is, unless a measurement was performed, the particle's location or momentum was unknown. Heisenberg accordingly made his famous and oft-quoted reply that a physicist cannot predict or explain what happens between observations.[28] (Recall that in classical physics a measurement was not always required to antecedently know a subsequent result.) Thus, knowledge about atomic entities depends upon observation and any claim about such entities is an unverifiable

speculation when no measurement is performed. (Of course, there are exceptions.) In short, atomic knowledge is often restricted to only what can be observed and then that information is gained only with an interaction and modification of the observed.

Heisenberg concluded that "atomic object *per se*" was reduced to the "object as observed," i.e., the object dependent upon the character and effect of observation. The epistemological consequence was significant.

> [The loss of classical realism occurred] because quantum theory made the atom inaccessible to our senses or our imagination, unlike objects within our daily experience. An atom or, more correctly, the smallest unit of modern nuclear physics, an electron no longer displays "in itself" ("*an sich*") even the simplest geometrical and mechanical properties but it shows them only to the extent to which they can be made accessible to observation by external interference.[29]

With the replacement of the object *an sich* by the "object as observed," (or the "object *fur uns*") Heisenberg renounced classical objectivity. Also, with the collapse of the classical premises of absolute space and time (which had allowed for a *nonrelative* frame of reference), both the special theory of relativity and quantum theory had encouraged the dependence and relativity of the observed upon the observer.

> . . . the scientist will once and for all have to renounce all thought of an objective time scale common to all observers, and of objective events in time and space independent of observations of them. Perhaps [these] recent developments represent only a passing crisis. I tend to the opinion, for which there seems to be the strongest evidence that this renunciation will be final.[30]

Thus, Heisenberg advocated that the object *per se* be replaced by the "object in a particular experimental context." That is, an atomic object does not possess intrinsic and autonomous properties (except for electrical charge) since the observed properties were partially the result of the particular structure of observation. For example, if an

ensemble of electrons were sent through a multi-slit apparatus, then the electron would manifest wave properties. On the other hand, if the electrons were sent through a bubble chamber, then particle properties would appear. Thus, all descriptions of intrinsic properties, or the object an sich, must be avoided, Heisenberg argued. (Heisenberg's usage of the object-in-itself obviously is not identical to Kant's "object an sich".)

Heisenberg claimed that the "dividing line" between the observed object and the other components of the experimental situation was arbitrary. An electron may in some situations be considered a microscopic particle, or it may be described as a macroscopic mark upon a photographic plate. In short, the dividing line between the observer, the observing apparatus and the object was not strictly, physically defined. The demarcation between observed and observer then was arbitrary. In certain situations, the electron may more appropriately represent a "union of apparatus and atomic object" while in other times, the electron may clearly be thought of as a "single, isolated particle." Since the dividing line was arbitrary, the broadest description would involve the observer's manipulations, the observing apparatus and the physical system under investigation. An "observation" or a "phenomenon" signified all of these components, although physicists would usually use the classical abbreviation and speak as though the electron only meant a particle (or a wave) that was independent of the apparatus.

Heisenberg on Positivism and Realism in Quantum Theory

Earlier, the Projection Postulate was described as the condition where a general "state vector" is a superposition, or specific collection, of several distinct eigenstates (or possible quantum states). Upon observation or an interaction with a macroscopic instrument, this superposition "collapses" into one determinate eigenstate. Heisenberg described this discontinuity as "the transition from the "possible" to the "actual"."[31] With this effect upon the system, the object was considered a part of the observed (i.e., the "dividing line" can include the observer). Numerous physicists and philosophers concluded that modern physics now involved a "subjective part."

> [The arbitrary dividing line] again emphasizes a subjective element in the description of atomic events, since the measuring device has been constructed by the observer, and we have to remember that what we observe is not nature itself but nature exposed to our method of questioning.[32]

Realist scientists and philosophers interpreted such remarks as signifying subjectivism within modern physics.

Heisenberg responded, on the contrary, that this "subjectivism" was not the idealist version and instead signified the new physical dimension of observation.

> [Measurement] applies to the physical, not the psychical, act of observation, and we may say that the transition from the "possible" to the "actual" takes place as soon as the interaction of the object with the measuring device, and thereby with the rest of the world has come into play; it is not connected with the act of registration of the result by the mind of the observer.[33]

While atomic physics avoids ". . . genuine subjective features [and] . . . does not introduce the mind of the physicist as a part of the

atomic event,"[34] Heisenberg claimed that quantum theory cannot obtain the classical ideal of objectivity, or an object independent of the observer. Quantum theory was subjective only in the sense that the properties of the atomic object partially resulted from the observation. Therefore, Heisenberg believed that quantum theory was neither classically subjective or objective, yet it contained "elements" of both. Quantum theory was objective but only in a new, restricted and nonclassical way.

While Heisenberg avoided the traditional categories of subjectivism and objectivism, he also rejected (conventional) positivism. Heisenberg saw positivism as ". . . based on the sensual perceptions of the observer as the elements of reality . . ."[35] Since quantum theory makes no reference to perceptions or the sensuous constitution of the observer, Heisenberg thought that this phenomenalistic concept also could not be utilized. Nevertheless, if positivism is not restricted to the perceptions of the observer and instead signifies the physical role and conditions of observation that ground and verify knowledge claims, then Heisenberg would concede that atomic physics was positivist. If positivism is the negation of d'Espagnat's definition of physical realism (viz., that the observed natural regularities exist (completely) independently of observation), then the Copenhagen Interpretation is a form of positivism.

While Heisenberg thought that the conventional notions of subjectivism, positivism and objectivism were too general and not completely suitable for physical and conceptual analysis, traditional realism, on the other hand, could clearly be rejected. Heisenberg

thought that classical realism and objectivity originated from Descartes' ontology. The Cartesian partitions between world and spirit, and between mind and body, encouraged the belief that objective knowledge could transcend reference to the human realm. Since the natural world was considered to be entirely independent from human activity, consciousness and culture, a truly objective science would describe and explain natural processes free of observer bias and effect.

> . . . in natural science the partition was for several centuries extremely successful. The mechanics of Newton and all the other parts of classical physics constructed after its model started from the assumption that one can describe the world without speaking about God or ourselves. This possibility soon seemed almost a necessary condition for natural science in general.[36]

As described in Chapter One, Popper also created a three world ontology in order to disjoin the realms of objective knowledge and the physical world from the subjective domain. Motivated by a (quasi) a priori notion of objectivity and realism, Popper's ontology clearly paralleled the classical partition of human from the nonhuman. He also (intentionally) followed the classical belief that such dichotomized ontology was (apparently) a necessary condition for natural science.

Historically, modern physics represents the most significant scientific challenge to these classical dichotomies. While dialectical materialism also united human knowledge, consciousness, and culture with "natural, material" processes, quantum theory was the first internal (to natural science) break from these dichotomies and requirements. Heisenberg countered that natural science does not describe an "ontologically pure" nature but rather:

> . . . it is a part of the interplay between nature and ourselves. This was a possibility of which Descartes could not have thought, but it makes the sharp separation between the world and the I impossible.[37]

Heisenberg concluded that the conceptual attack by numerous physicists and philosophers on the Copenhagen Interpretation was usually not motivated by specific empirical problems but by philosophical problems and, in specific, "dogmatic realism." Heisenberg defined dogmatic realism as the belief that all statements about the physical world can be "objectivated." He said, "We 'objectivate' a statement if we claim that its content does not depend on the conditions under which it can be verified."[38] The Copenhagen Interpretation suspended this requirement since atomic objects are often dependent on the experimental conditions. Since the dividing line between the observed and the observation is arbitrary, the experimental conditions can be considered to be linked to the object. Thus, not all statements can be objectivated and the requirements of dogmatic realism are unobtainable.

Niels Bohr and the Notion of Phenomenon or Wholeness

The Copenhagen Interpretation of quantum physics is often associated with Heisenberg's views. However, Niels Bohr's views were significantly more subtle and "revolutionary" than the Heisenberg position. Despite the unification and identification of Bohr and Heisenberg with the Copenhagen Interpretation, Bohr's views were much more advanced and consistent than Heisenberg's philosophy. As Abner Shimony pointed out, Heisenberg often unwittingly lapsed into metaphysical pronouncements and made uncritical epistemological

claims.[39] For example, although Heisenberg criticized the traditional metaphysics of nature, he considered the "transition of the possible to the actual" as a confirmation of Aristotle's potentia concept. Heisenberg thought that (some) natural processes evolved from discrete (quantum), potential states that later assumed a determinate actuality. Thus, nature consists of the actualization of certain potentia or tendencies. Bohr realized, on the other hand, that with the problems of classical realism and with the temporary adoption of instrumentalism, scientists should abstain from such metaphysical comparisons.

A more significant problem of Heisenberg's interpretation involved the "disturbance principle." Bohr realized that the discussion of "an observer" with "an apparatus" who unavoidably "disturbs" the "observed objects" still maintained the classical dichotomies and concepts. Bohr replaced this traditional language usage with an entirely novel concept of "wholeness." This idea is a prominent part of the challenge to Einstein and Popper's realism.

Whereas Heisenberg audaciously denounced the Cartesian partition of observer-observed and subject-object, Bohr handled this issue with hesitant circumspection. Bohr did not deny that quantum theory offered substantial grounds for a novel observer-observed relation. Yet, he avoided facile pronouncements since the subject-object dichotomy seemed necessary for clear, unambiguous empirical descriptions. Science would be impaired without the general differentiation of the observed system from subjective factors.

> Thus Bohr speaks of drawing a necessary but arbitrary distinction between observing and observed systems. This distinction is "necessary" because in order to describe unambiguously an interaction as an observation of a

> particular object, the distinction between it and the agency of observation must be stipulated. But where that distinction is made is "arbitrary," in the sense that there is no theoretical way to define the classical mechanical state of the systems thus distinguished. "Observing system" and "observed object" are terms which are well defined only in the context of a particular description of an interaction. Hence they must be regarded as descriptive categories invoked for an unambiguous communication of the results of an observation rather than as referring to different constituents of nature. Although the distinction between observing system and observed object is arbitrary from the physical point of view, the context in which the description of a phenomenon is to be employed in science effectively determines the particular distinction which is made.[40]

Whereas Heisenberg emphasized the arbitrariness of the dichotomy, Bohr said that unambiguous statements necessitated the distinction. Bohr supported the traditional attempt to understand physical nature as "external" to consciousness.

Henry Folse described how Bohr replaced the "disturbance principle" with "wholeness" after Einstein's challenge to the Copenhagen Interpretation. Bohr saw that Einstein used a problematic "hidden notion of physical reality" which helped to clarify a fundamental issue. Indeed, Bohr and especially Heisenberg both initially used the "disturbance principle" (i.e., the observer disturbs the observed) in classical terms. As mentioned above, the disturbance language still denoted an independent entity (the experimenter) that disturbs another autonomous entity (the atomic object) by the use of another physically separate component (the apparatus). Bohr realized that this description still attributed a complete autonomy to objects and their respective properties despite the obstacles raised by quantum theory. Bohr concluded that an entirely revised and reformed understanding of "phenomenon" was necessary.

The EPR helped to reveal the incompatibility of some of these fundamental concepts and premises of classical and quantum physics. Briefly stated and expanded below, Einstein argued that quantum theory was incomplete since, for example, an electron has both momentum and position although quantum theory could only specify a single conjugate property at a time. Since the observer could choose to measure either momentum or position, the object definitely possessed both attributes. Yet, quantum theory could determine only one value. Therefore, a more "complete" theory should specify all values.

Bohr thought that Einstein was attempting to prove a contradiction in quantum theory by classical premises. Bohr countered that in quantum mechanics, for example, wave and particle attibutes were not the inherent and autonomous properties of the object. A wave phenomenon is the synthesis of a particular arrangement (e.g., a two-slit device) united with an ensemble of atomic objects. The "phenomenon" was the entire physical arrangement. Thus, when Einstein posed the choice between two properties of a single object, Bohr argued that two entirely different (yet complementary) phenomena were involved, rather than one object. The arrangement that produced waves was a distinct physical phenomenon from the arrangement that involved "particle behavior." Bohr argued that Einstein was actually describing two different events, rather than a single object with various intrinsic properties.

With "phenomenon" now denoting the entire experimental context united with certain atomic objects, Bohr shifted the emphasis from the "interaction and interference" of the object (or "the collapse of the

wave packet") to the conditions that produced the phenomenon (when any quantum state was involved).

> From our point of view we now see that the wording of the above-mentioned criterion of physical reality proposed by Einstein, Podolsky, and Rosen contains an ambiguity as regards the meaning of the expression 'without in any way disturbing a system.' Of course there is in a case like that just considered no question of a mechanical disturbance of the system under investigation during the last critical stage of the measuring procedure. But even at this stage there is essentially the question of an influence on the very conditions which define the possible types of predictions regarding the future behaviour of the system.[41] (added emphasis)

In classical and modern physics, phenomenon generally signified the appearance of an object (or collection of objects). Phenomenon now denotes the observed object and the conditions of appearance.

Summarizing Bohr's view of the "disturbance and observation problem," Clifford Hooker stated,

> Bohr utterly rejected the temptation to carry the classical presuppositions across to the quantum domain and hence (i) speak of the existence of the quantum of action as providing an uncontrollable disturbance of the observed system and (ii) claim that merely our knowledge of atomic systems is limited in the manner indicated by the uncertainty relations (as if there was merely an informational barrier built into the world). It is true that Bohr occasionally spoke thus, and most other physicists do all the time; but most of the time, especially when he concentrated on elucidating his conception of measurement, Bohr flatly denied the applicability of the classical notion of "disturbance" of a system and emphasized the "wholeness" of the measuring apparatus-object situation. The two are "indivisibly (=unanalyzably) linked" during the interaction, so that it is impossible in principle to separate off object from apparatus. The "impossible in principle" here should not be read merely as "physically impossible," but as the much stronger "descriptively, or conceptually, incoherent." It is not that some disturbance is incalcuable but that the entire concept of two things, apparatus and object, each having its properties autonomously, is a logically improper analysis of the descriptive process. . . .The object cannot be ascribed as an "independent reality in the ordinary physical sense."[42]

Despite Bohr's cogent argument, I will often use the interaction-disturbance language. Since most of the literature uses this language, I will uphold their usage to provide continuity rather than continually qualifying their remarks (with Bohr's "improved" usage). This language confusion should not detract from the analysis of Popper's critique of modern physics.

Wholeness, Nonlocality and the Challenge to Classical Realism

In the next chapter, the EPR paradox will be discussed at length since it was prominent in Popper's attempt to undercut the orthodox interpretation and to reestablish a classical realist view of science. This section provides a brief conceptual framework for this important argument and experiment. Bohr's novel notion of phenomenon or wholeness will become important in the EPR debate. Einstein's paradox revealed that either quantum theory violated locality or, on the other hand, it must be incomplete (and unnecessarily emphasized the observer's disturbance). Briefly stated, the violation of locality is paradoxical since the measurement of a separated, noninteracting system should not "influence" another nonlocal system. (The two systems initially formed a "singlet" or unified state and then were allowed to separate an arbitrarily large distance.)

In response to Einstein's argument, Bohr developed his wholeness concept. This concept sought to undercut the classical premises of the argument which allowed a paradoxical, even absurd conclusion. Bohr claimed that Einstein's conceptual premises prevented his comprehension of the true orthodox position. Clifford Hooker remarked that:

> Einstein was looking for an answer, <u>a substantial physical explanation offered in the terms of the traditional conception of physical reality</u>, . . . to the problem of locality which quantum theory raised, whereas Bohr's reply slices through this problem at the conceptual level.[43]

The paradox of locality was undercut by Bohr's notion of the "indivisible experimental unity." In Einstein's argument, the separated particles and the measuring apparatus were viewed as (at least) three separate components. The measurement and corresponding value of one particle then should not physically influence the values of the other nonlocalized particle. One particle was believed to <u>independently</u> possess both momentum and position values. After their interaction and separation, the nonlocal particles were autonomous and the measured values should not reflect a direct correlation.

Due to the arbitrary dividing line, Bohr argued that quantum theory does not allow Einstein's separation of the observed object from the apparatus (that was partially responsible for the particular observed properties). <u>More importantly, the two particles (in this special case) should not be considered as distinct objects but rather a part of the entire system</u>. That is, the experimental totality signified for Bohr the observer's manipulations, the apparatus and all objects of the singlet system regardless of their relative locations. Together they form a phenomenon and quantum theory prohibited Einstein's demarcation between the various components (and especially the nonlocalized particles). On the contrary, Einstein possessed a classical ontology of objects: distinct objects (even from a singlet state) are independent and possess autonomous properties (beyond the influence of the apparatus and the condition of the other particle).

Bohr thought these premises were responsible for the subsequent misunderstanding of "observer disturbance" and nonlocalized objects.

> There is no "disturbance" present here in the classical sense of a change of properties from one as yet unknown value of some autonomously possessed physical magnitude to a distinct value of that magnitude under the causal action of the measuring instrument. Even talk of change of properties, or creation of properties, is logically out of place here because it presupposes some autonomously existing atomic world which is describable independently of our experimental investigation of it. There is not such world for Bohr. It is not that Bohr does not take the reality of the atomic domain seriously, but rather that our knowledge of that world, and therefore . . . our ability to describe (conceptually comprehend) its nature, gained through the experiments we can conduct, is limited.[44]

Bohr concluded that the problems of nonlocality or observer disturbance existed due to the classical conceptual constraints. Quantum theory is paradoxical and problematic in juxtaposition to classical concepts and thus the classical (and not quantum) premises and constraints must be revised. With this revision, a transformation of the traditional concepts of causality, determinism, object, space-time and observation will occur. Bohr thought that this extensive revision signified the end of "classical reality."

> The apparent contradiction [raised by EPR] in fact discloses only an essential inadequacy of the customary viewpoint of natural philosophy for a rational account of physical phenomena of the type with which we are concerned with in quantum mechanics . . . . The very existence of the quantum of action entails . . . the necessity of a final renunciation of the classical ideal of causality and a radical revision of our attitude towards the problem of physical reality. In fact, as we shall see, a criterion of reality like that proposed by the named authors contains--however cautious its formulation may appear--an essential ambiguity when it is applied to the actual problems with which we are here concerned.[45] (added emphasis)

In summary, realists such as Popper and Einstein were convinced that the EPR paradox demonstrated the inadequacy of (the Copenhagen

Interpretation of) quantum theory. The violation of locality played a huge role in revealing the paradoxical, "incomplete" reasoning of quantum mechanics. By an analysis of the conceptual foundations of the argument, Bohr manifested certain premises that motivated and maintained the realist view. These premises were actually not necessary for physical analysis and in fact received strong strictures from quantum theory. At this juncture, I will now discuss Popper's detailed attack upon the Copenhagen Interpretation that strove to uphold classical realism.

Notes

[1] Alvin Hudson and Rex Nelson, University Physics (New York: Harcourt Brace Jananovich, Inc., 1982) 870.

[2] Clifford Hooker, "The Nature of Quantum Mechanical Reality," Paradigms and Paradoxes, ed. R.G. Colodny (Pittsburgh: University of Pittsburg Press, 1972) 71.

[3] Simon Laplace, quoted by F.A. Wolf in Taking the Quantum Leap (San Francisco: Harper and Row, 1981) 43.

[4] Clifford Hooker, op.cit., 71-2.

[5] Hilary Putnam, "A Philosopher Looks At Quantum Mechanics," Beyond the Edge of Certainty, ed. R.G. Colodny (Englewood Cliffs: Prentice-Hall, 1965) 79.

[6] Paul Davies, Other Worlds (New York: Simon and Schuster, 1980) 58.

[7] Ibid., 20.

[8] Steven Toulmin, Architecture of Matter (Chicago: University of Chicago Press, 1962) 270.

[9] Ibid., 274-5.

[10] Niels Bohr, quoted by A. Hudson and R. Nelson, op.cit., 914.

11 Paul Davies, op.cit., 58.

12 N.R. Hanson

13 A.P. French and Edwin Taylor, An Introduction to Quantum Physics (New York: W.W. Norton and Inc., 1978) 243.

14 R. Shankar, Principles of Quantum Mechanics (New York: Plenum Press, 1980) 120.

15 Hilary Putnam, op.cit., 77.

16 Werner Heisenberg, quoted by A.P. Taylor and Edwin French, op.cit., 287.

17 Heinz Pagels, The Cosmic Code, (New York: Bantam Books, 1982) 114.

18 Karl Popper, Conjectures and Refutations (New York: Harper and Row, 1968) 100.

19 Richard Schlegel, Superposition and Interaction (Chicago: University of Chicago Press, 1980) 223.

20 Mario Bunge, "The Turn of the Tide," Quantum Theory and Reality, ed. M. Bunge (New York: Springer-Verlag, 1967) 3.

21 Ibid., 3.

22 Paul Feyerabend, "On a Recent Critique of Complementarity: Part I," Philosophy of Science 35 (1968): 310.

23 Werner Heisenberg, Physics and Philosophy (New York: Harper and Row, 1958) 28.

24 Werner Heisenberg, Philosophic Problems of Nuclear Science (Greenwich, Conn.: Fawcett Publications, 1952) 12.

25 Ibid., 96-7.

26 Ibid., 97.

27 Ibid., 98.

28 Werner Heisenberg, op.cit., 54.

29 Werner Heisenberg, Philosophic Problems in Nuclear Science, 97.

30 Ibid., 17-8.

31 Werner Heisenberg, Physics and Philosophy, 54.

[32] *Ibid.*, 58.

[33] *Ibid.*, 55.

[34] *Ibid.*, 55.

[35] *Ibid.*, 145.

[36] *Ibid.*, 81.

[37] *Ibid.*, 81.

[38] *Ibid.*, 81-2.

[39] Abner Shimony, "Bohr, Heisenberg, Schrodinger," *Physics, Philosophy and Psychoanalysis* eds. R. S. Cohen and L. Laudan (Dordrecht, Holland: D. Reidd Publishing Company, 1983) 212.

[40] Henry J. Folse, *The Philosophy of Niels Bohr* (Amsterdam: North Holland Physics Publishing, 1985) 162-3.

[41] Niels Bohr, "Can Quantum Mechanical Description of Physical Reality be Considered Complete?," *Physical Review* 48 (1935) 700.

[42] Clifford A. Hooker, "The Nature of Quantum Mechanical Reality," *Paradigms and Paradoxes: The Philosophic Challenge of the Quantum Domain*, ed. Robert Colodny (Pittsburgh: Univeristy of Pittsburg, 1972) 156-7.

[43] *Ibid.*, 148.

[44] *Ibid.*, 155.

[45] Niels Bohr, *op.cit.*, 696-7.

CHAPTER THREE

POPPER'S ATTACK ON THE NONREALISM OF MODERN PHYSICS: "TO EXORCISE THE OBSERVER . . ."

The Nature and Breadth of Popper's Critique

In the mid-twentieth century, Karl Popper encouraged the demise of logical positivism and supported the renewal of realism. Despite this transition within philosophy, Popper thought that a more significant conceptual clash was unfolding in modern physics. A converse transition in the ideology and interpretation of physics occurred as classical realism was controverted and replaced by a quasi-positivism. Since Popper considered realism as a major impetus for science growth, he feared that a unprecedented conceptual inertia in science began. The positivism and instrumentalism of the Copenhagen Interpretation thus signified a crisis:

> A very serious situation has arisen. The general antirationalist atmosphere which has become a major menace of our time, and which to combat is the duty of every thinker who cares for the traditions of our civilization, has led to a most serious deterioration of the standards of scientific discussion. It is all connected with the difficulties of the [quantum] theory--or rather, not so much with the difficulties of the theory itself as with the difficulties of the new techniques which threaten to engulf the theory. It started with the brilliant young physicists who gloried in their mastery of the tools and looked down upon us amateurs who had to struggle to understand what they were doing and saying. It became a menace when this attitude hardened into a kind of professional etiquette.[1]

For Popper, science is perhaps the greatest human achievement and realism is an inviolate premise of science. Consequently, when scientists rescind such basic principles, a dangerous situation can occur as the nature of scientific rationality and activity is impugned.

> I came to conclusion that our standards of rational discussion have seriously deteriorated. . . . The decline started with the first World War and with the growth of the technical and instrumental attitude toward science.[2]

Popper considered the "problem of observation and measurement" as the chief source of anti-realism in modern physics, although other factors have contributed. As we have seen, this problem involves the new physical role and effect of measurement upon the observed in atomic physics. Since the "perturbation of the observed" is uncontrollable in many conditions, the experimental set-up must be taken into account. Many physicists considered the properties of the object to be often inextricably linked to the conditions and effects of observation to the extent that a clear distinction between object and observation was difficult and often impossible.

Since the observed entity was not autonomous from the observing conditions, physicists claimed that atomic physicists did not address the object per se, or the "true ontological object" but rather the object as manipulated and disturbed by the scientist. Thus, the realist notion of an "independent, autonomous reality with definite real objects" lost its former meaning and became a conceptual abstraction. Scientists such as Heisenberg concluded that physics does not describe nature itself but nature as manipulated by limited human means.

This empirical development and interpretation obviously paralleled the conceptual views promulgated by logical positivists where the

notions of "independent real world" and "the true object independent of observation" were meaningless. Physicists now agreed that statements and concepts were legitimate only in reference to observational and verifiable conditions. The "ontological character" of classical realism, with its unqualified reference to the existence of forces, particles and laws, was replaced by instrumentalism. That is, a particle was often considered as a conceptual device and the result of a specific experimental situation and observation, and not necessarily an veridical reflection of physical reality.

Popper sought to purge this anti-realism with a direct attack upon the empirical basis of the Copenhagen Interpretation and its "observer-oriented" views rather than with a purely philosophical denouciation. He attempted a renewal of the classical view of observation and realism by exorcising an "anti-realistic ghost":

> This is an attempt to exorcise the ghost called "consciousness" or "the observer" from quantum mechanics, and to show that quantum mechanics is as "objective" a theory as, say, classical statistical mechanics. My thesis is that the observer, or better, the experimentalist plays in quantum theory exactly the same role as in classical physics. <u>His task is to test the theory</u>.
>
> The opposite view, usually called the Copenhagen Interpretation of quantum mechanics, is almost universally accepted. In brief it says that "objective reality has evaporated," and that quantum mechanics does not represent particles but rather our knowledge, our observations, or our consciousness, of particles.[3]

Popper believed that the contemporary interpretation of physics also involved a greater horror than the suspension of realism but also included subjectivism. Some physicists (such as Heitler and Wigner) thought that not only did the observed depend upon the conditions of observation but also upon the conscious decisions and choices of the

observer. For example, it has been proposed that the "wave packet does not collapse" until a conscious observation. Popper took this minority view as representative of the demise of scientific objectivity and an uninhibited embrace of subjectivism.

I will now describe Popper's broad and detailed critique of the Copenhagen Interpretation's "harmful" anti-realism. His critique was unquestionably a noteworthy endeavor as he attempted to revive classical realism while simultaneously undercutting quantum theory's instrumentalism and positivism, along with various subjectivist accounts of the theory. Popper focused upon the empirical principles and postulates, reinterpreting the Principle of Complementarity and the subjectivist account of indeterminism and probability while proposing "objectivist and realist" alternatives such as his Propensity theory. While Popper believed that the current "physical theory and its formalism is unbelievably successful,"4 he thought that the interpretation of the formalism was entirely misconceived. Numerous muddles burdened the application of the formalism and thus the interpretative superstructure had to be amputated from the "core theory." In short, the Copenhagen Interpretation possessed:

> . . . three articles of faith--duality, uncertainty, and complementarity; and in addition, with all those other gratuitous quantum mysteries and horrors such as the subject-object confusion, the "transition from the possible to the actual" [i.e., the Projection Postulate] as a consequence of our measurements, and quantum jumps.[5]

Key premises and features of Popper's commonsense realism became explicit in his critique of the Copenhagen Interpretation. His specific arguments and proposals gave concrete content to a realist formulation of a physical theory. For example, his argument against quantum

theory's purported "completeness" and the "observer's new role" led Popper to embrace the EPR thought-experiment which attempted to reaffirm the objectivity and realism of classical physics. This thought experiment, which was recently performed, crystallized and consolidated Popper's views concerning the relation between science and classical realism and, I believe, demonstrated the various limitations of commonsense realism.

The Objectivity of Quantum Mechanics

In order to "exorcise the ghost" that threatened the realism of modern physics, Popper suggested a simple philosophical thought-experiment that would show that the practice of quantum mechanics is indistinguishable from classical mechanics. Popper's thought experiment was a response to Walter Heitler's claim that the division between the conscious observer and the physical world was now untenable. This claim obviously contradicted the realist view that physical reality is ontologically autonomous from human activity, consciousness and manipulation.

The first part of Popper's thought-experiment used a classical arrangement with a measuring apparatus inside a sealed box. The box and its self-registering mechanism was closed and an experiment was performed automatically within the box. Shortly, the box ejected a print-out of the experiment's measurement. The measurements then were compared with the theory's prediction.

The second part of Popper's thought-experiment was similar except that many identical boxes were necessary. The many identical boxes here

imitate quantum theory's statistical character. (As a statistical theory, quantum theory's laws are predictions about many identical trials and their statistical tendencies; in contrast, classical physics could often make specific, definite predictions about an individual event.) Each box in the battery automatically performed the experiment and issued a measurement print-out. The statistical distribution from all of the boxes was then compared with the theory's predictions. The accurancy of classical mechanics and quantum mechanics is great enough that both experiments can be predicted within attainable limits. Popper then asked: what was the observer's relation to the results? More fundamentally, were the values assumed by the physical objects independent of human determination?

Popper argued that no observer was necessary for the essential part of the experiment. The self-registering apparatus performed all operations inside a sealed container and later issued out the measurements. No conscious observer interacted with the object in the box since the box was completely isolated. The second experiment was indistinguishable from the first, except for the additional boxes that were necessary because of quantum theory's statistical nature where many trials "identically prepared" are run. The observer played no essential role in the first or second part of the experiment. Popper concluded that "Quantum theory is exactly as objective as any other physical theory."[6] Consequently, the realism and ontology of classical science remains untransformed.

Popper similarly remarked that the experimental practice of the quantum physicist is indistinguishable from the classical physicist.

> Most experimentalists, though much concerned with the limits of precision of their results, do not seem to be more worried about the role of the observer or about interfering with their results than they are in connection with sensitive classical experiments.[7]

Scientists do not call an electron "my observation of an electron-like phenomena." Scientific descriptions have only minimal reference to experimental (observer) disturbance. Popper subsequently thought that the Copenhagen Interpretation's emphasis upon the observer and its subsequent anti-realism arose from its superfluous conceptual superstructure.

Copenhagen's Conceptual Confusion

Before discussing Popper's scientific critique of Bohr's ideas, it is important to first note Popper's more general philosophical criticism. Popper thought that Bohr had committed a common philosophical mistake by failing to differentiate between theories and concepts. First of all, a concept is equivalent to a definition and a (mental) picture. A theory, on the other hand, is a statement about something. "It is most important to distinguish between statements and words, and between theories and concepts."[8]

Popper claimed that words are basically inessential and can be altered without profound consequence. Theories, on the other hand, are the core and focus of scientific activity. Theories are testable statements about the world and are the vehicles of scientific progress. Concepts, or definitions, are mostly arbitrary, and arguments about them are usually irrelevant. Popper's opposition to positivism was apparent:

genuine epistemology should not focus upon concepts and their meanings, but with theories and their truth.

The importance of this distinction pertains directly to Bohr's emphasis upon concepts and pictures. The Principle of Complementarity was based upon the coherence (yet incommensurability) of the particle-wave concepts. Popper thought that the Principle of Complementarity had allowed a theoretical impasse with the thesis that atomic objects were impossible to understand because the concepts were partial and inadequate. (Fundamental atomic concepts, such as particles and waves, could only partially explain certain phenomena and were totally inadequate to explain other complementary phenomena.) After its acceptance, the particle-wave dualism was not challenged since physicists thought that the dualism was conceptually not understandable; thus, the issue was unresolvable and insuperable. Popper believed that physicists (unintentionally) prevented the emergence of new theories by accepting this conceptual dilemma. Popper remarked,

> The fashionable thesis that it is in vain to try to "understand" modern physical theories because they are essentially "ununderstandable" (though useful instruments for calculation) amounts to the somewhat absurd assertion that we cannot know what problems they are intended to solve, or why they solve them better, or worse, than their competitors.[9]

Theories are not necessarily visual images or pictures; they can be completely abstract formalisms without visual relation to the physical world. Yet, if testable, they could be an accurate description of a physical process.

Popper claimed that instrumentalist views abounded because of the incessant emphasis upon pictures, with the concurrent failure (i.e., limitations) of these pictures (e.g., the classical wave picture).

Physicists concluded that truth and understanding (in the traditional sense) were "out of the picture," and theories could only be tools. Popper's specific advice followed from his general philosophic view: avoid conceptual analysis and simply test the theories along with competitors. Popper feared the abdication of competitors to the orthodox view of quantum mechanics.

Popper and the Principle of Complementarity

Popper attempted to reinstate the philosophical premises of classical physics by reinterpreting critical empirical principles and hypotheses such as the Principle of Complementarity. This principle epitomized for Popper many detrimental aspects of the Copenhagen Interpretation such as the instrumentalist use of theories, the nonrealist interpretation of atomic objects, the misuse of concepts, the new "subjectivist tendency" in physics and the like. In the "Three Views of Human Knowledge," Popper used this principle as his main example of "sterile" instrumentalist propositions that "hasn't led to anything useful."

Popper's critique of the Principle of Complementarity was two-fold. The primary emphasis, discussed below, was scientific. The second attack was upon Complementarity's insecure philosophic foundations. Popper thought that Complementarity was simply an ad hoc device created by Bohr to circumvent the orthodoxy's problems. Instead of creating a new theory (motivated by the existing contradictions and problems), the orthodoxy fought to maintain the current position, viz., the Copenhagen Interpretation. Popper thought that the Principle of Complementarity

was the "ultimate" ad hoc creation, as it attempted a coup-de grace of all alternative theories - present and future. Complementarity "amounted to a renunciation of the attempt to interpret atomic theory as a description of anything."[10] This principle embraced opposites and paradoxes on the grounds that a simple, logical description was inadequate; scientific understanding and theories had reached the limits of common reason. To "understand" was now relegated to a metaphysical and superfluous level. Yet, Popper countered that this vitiation of scientific understanding annulled all attempts to overturn the existing theory and its dilemmas. He argued that new theories were not considered and a concomitant dormant instrumentalism arose. Since "scientific understanding was impossible," instrumentalism avoided discussions about truth and falsity and thus was consistent with Complementarity, since true physical descriptions were now considered suspect. Consequently, the Principle of Complementarity represented a chief anti-realistic force within physical interpretation.

Complementarity pointed to the paradoxical inadequacies of the subject's reason and perceptual capabilities. More succinctly, advocates of this view often claimed that nature appeared contradictory and paradoxical since human comprehension was limited. Descriptions of nature remained within a limited (classical) discourse since humans can (purportedly) understand no other language (see Chapter 2). Popper's view on concepts and theories directly addressed this problem: the emphasis upon mental inabilities arose from the desire to acquire purer concepts and pictures of natural processes. Bohr wanted to comprehend pictorially, with concepts free from contradiction. Since such

comprehension proved problematic, an "epistemic nihilism" arose. Yet, Popper argued that the scientific quest should not be for conceptual purity, but simply prolific theories. Theories, aspiring to verisimilitude, should be refutable, although not necessarily pictorial, and can be totally abstract, mathematical systems. For Popper, there must be a continual succession of new theories rather than a stagnant acquiescence under the view that further understanding is futile. Complementarity, in Popper's view, arose only because of this impossible endeavor to think nature purely, i.e., consistently without paradoxes. On the contrary, problems and dilemmas have been the very impetus of scientific progress since weak and problematic theories motivate the creation of better theories. Bohr "short-circuited" such progress and impaired the opposing theories. As Popper said,

> These considerations are important because of endless talk about the "particle picture" and the "wave picture" and their alleged "duality" or "complementarity" and about the alleged necessity, asserted by Bohr, of using "classical pictures" because of the (admitted but irrelevant) difficulty, or perhaps impossibility, of "visualizing" and thus "understanding" is of little value; and the denial that we can understand quantum theory has had the most appalling repercussions, both on the teaching and on the real understanding of the theory.[11]

Popper's realism and his emphasis upon progress (theory development) was the motivating force here. He thought that theories must attempt the impossible: to truthfully explain the "real stuff" of the universe. One might ask, "what is scientifically real for Popper?" Yet, Popper ventured a suggestion: the physically real is that which is "kickable, and able to kick back if kicked, though there are . . . degrees of kickability: we can't kick quasars, David Bohm reminds me."[12]

I will return to this classical account of realism when evaluating Popper's overall scientific philosophy.

Probability and Subjectivism in Quantum Mechanics

Popper thought that the subjectivism of quantum mechanics also emerged from sources other than the "observer's new role." The probabilistic, statistical character of quantum mechanics significantly influenced the Copenhagen Interpretation. Recall that quantum mechanical laws usually cannot predict single atomic events but give a statistical prediction of many similar events. Within classical mechanics, amazingly accurate single-event predictions were possible. However, due to the Uncertainty Principle and other factors, such accuracy in atomic physics has not been obtainable.

> In its place, quantum mechanics offers only probability estimates. If a series of identical measurements are made of a property of a system, quantum mechanics can predict precisely the average value of these measurements, yet it can give only a probability estimate for any single measurement.[13]

Popper thought that this probabilistic nature of atomic knowledge was interpreted inappropriately by the orthodox position. In brief, the Copenhagen Interpretation attributed the lack of certainty and mere probability to the subject's lack of knowledge. Popper thought, to the contrary, that the probabilistic nature of atomic physics pertained to the statistical character of the actual micro-events themselves. Discussed below, the statistical character of atomic events has been responsible for the Uncertainty Principle, rather than the converse. Popper thought that if he could subsume Heisenberg's principle under statistical law, another major source of subjectivism would be undercut.

Initially, Popper's first thesis in "Quantum Mechanics without 'the Observer'" appeared to be mundane. But for Popper, it "concerns the most important thing for understanding quantum theory."[14] Popper continually referred back to this idea: the roots of atomic theory were statistical. All of the ground-breaking experiments and their theoretical explanations involved nonsingular events; more precisely, many particles were used and the subsequent laws were generalizations about their statistical tendencies. These laws did not explain the behavior of an individual photon or electron but rather the distribution of the ensemble.

> That the quantum theory should be interpreted statistically was suggested by various aspects of the problem situation. Its most important task--the deduction of the atomic spectra--had to be regarded as a statistical task ever since Einstein's hypothesis of photons. . . . For this hypothesis interpreted the observed light effects as mass phenomena are due to the incidence of many photons.[15]

In addition, Schroedinger's equation and wave mechanics, which were pivotal for quantum mechanic's development, did not gain preeminence until Max Born's probabilistic interpretation of them.

Popper added that "statistical questions demand, essentially, statistical answers."[16] That is, "statistical conclusions cannot be obtained without statistical premises. And therefore answers to statistical questions cannot be obtained without a statistical theory."[17] Yet, physicists wrongly demanded nonstatistical, unique answers about individual, specific particles. Statistical distributions, however, cannot aid in the prediction of a single event. For example, a statistical distribution can fairly accurately predict

the number of people who will die within the month of May, but it cannot predict which individuals will die.

Popper thought that an essential fallacy and source of subjectivism within quantum theory was now exposed. That is, it was believed that the subject's lack of knowledge about individual particles had forced a probabilistic, indeterministic viewpoint. Due to the observer's insufficient knowledge, science was bereft of certitude. Thus, many concluded that the statistical theories were a subjectivist consequence of the observer's insufficient knowledge. Popper argued, to the contrary, that the foundations and problems of quantum theory were, from the beginning, probabilistic, and all consequences must necessarily be probabilistic; statistical conclusions must follow from statistical premises. By appealing to the subject and the subject's lack of knowledge, the original statistical foundation of the theory was forgotten.

Popper argued that the Heisenberg formulae must now be seen in their original statistical context. "I assert that these formulae are, beyond all doubt, validly derivable statistical formulae of the quantum theory."[18] The energy-time relation, for example, was derivable from Planck's quantum energy law; this law referred primarily to "statistical scatter of the energies of the photons which together form the spectral line."[19] Popper argued that the Heisenberg relations did not originally refer to the uncertainty and disturbance of a single particle, but rather the statistical "scatter" of particles.

> I . . . now interpret the [Heisenberg] formula as a singular probability statement, and therefore as determining the propensity of a single particle to "scatter"; it predicts that the actual statistical scattering will be observed if we

> <u>repeat</u> the experiment in question many times, each time with a single particle.[20]

Popper also pointed out that the Heisenberg relations are derivable from the Schroedinger equation, which is a probability equation (with Born's supplement).[21]

Popper concluded that: (1) the Heisenberg formulae emerged from statistical premises, (2) they were not applicable for an isolated, individual prediction (but rather the tendencies and propensities of a group of individual particles), (3) the Heisenberg formulae had acquired a false, single-particle interpretation, (4) the uncertainty of measurement of a single particle had no connection to the observer's disturbance, and (5) the probabilistic character of the Heisenberg relations was not the result of the observer's lack of knowledge. Heisenberg had claimed that knowledge is completely limited by the Uncertainty Principle and that it was futile to struggle against this restriction. Popper replied,

> If we start from the assumption that the formulae which are peculiar to quantum theory are probability hypotheses, and thus statistical statements, then it is difficult to see how prohibition of single events could be deduced from a statistical theory. The belief that single measurements can contradict the formulae of quantum physics seems logically untenable.[22]

He added,

> Indeed we can see that Heisenberg's comment have had a crippling effect on research. Connections which are not far to seek may easily be overlooked if it is continually repeated that the search for any such connections is "meaningless."[23]

Summarizing his view of probability theory, Popper stated,

> I uphold my positive thesis that the problem of interpreting quantum theory is bound up with that of interpreting probability theory.[24]

He added,

> I am more firmly convinced than ever that the lethal mixture of subjective and objective interpretations of probability has created all those irrationalist symptoms, such as the dream of the quantum theoretical interference of the subject with the object of knowledge.[25]

Thus, many scientists believed that the mere probabilistic nature of quantum theory, rather than a (classically) deterministic theory, originated from the lack of information of individual particles. The Uncertainty relations accordingly were not seen as giving a statistical distribution of particles, but as the limit of knowledge concerning any individual particle. This idea directly undercut the particle-trajectory notion. The notion of particle path became "metaphysical" and unknowable. Popper argued that this development added further confusion in the Copenhagen Interpretation. The Heisenberg relations created ambiguities, indeterminacy and faulty limits that circumvented existing problems. The orthodoxy claimed "completeness" since further specification of the unknown was impossible. Popper called it the "Great Quantum Muddle": the Uncertainty Principle became the limit of knowledge concerning individual events. Nevertheless, the Heisenberg Uncertainty relations have a complete dependence upon statistical theories (such as Planck's energy relations) and the uncertainty relations should not prohibit these <u>more fundamental</u> statistical theories. That is, the statistical theories established Heisenberg's principle; his principle should not retroactively restrict the statistical theories. (The use of probability theory in quantum mechanics will be expanded in the last section of this chapter in describing Popper's propensity theory. He thought that this theory

would give quantum theory a completely objective interpretation, and would remove "ghosts" such as the observer, the particle-wave duality, and the like.)

Popper's Attack on the Copenhagen Interpretation's "Completeness"

The "completeness" issue in quantum theory will play a paramount role in the analysis of Popper's commonsense realism. Popper's challenge to quantum theory's completeness consolidated his argument against nonrealism in physics. He thought that the empirical sources and tendency for positivism were patently falsified by a thought experiment by Einstein, Podolsky and Rosen. Popper's analysis of the EPR thought experiment and his reply after its recent testing, manifested key elements of his commonsense realism. Certain features and weaknesses that are not explicit in his purely philosophical essays on commonsense realism were revealed in his critique of nonrealism in physics. In short, while his commonsense realism may possess many strengths from an *a priori* philosophical standpoint, developments and discoveries within comtemporary physics raise serious problems with the specific premises and constraints of Popper's realism. *Accordingly, this dissertation will attempt to demonstrate certain key weaknesses of Popper's ontology on the basis of his conservative maintanence of classical concepts*.

The Copenhagen Interpretation held that the current knowledge about the microscopic domain was complete in several respects. Many scientists were convinced that the Uncertainty Principle signified insurpassable scientific barriers. Thus, certain fundamental aspects of

physical knowledge, such as the precise determination of particle path and behavior, were unattainable. "Completeness" signified then a negative predicament, i.e., physical and theoretical barriers, rather than a positive notion of completion and final solutions.

Popper found the notion of completeness inherently offensive even though completeness meant "insuperable limits" and not a "finished and final system." The belief in completeness suggested that no further breakthrough could overcome the Heisenberg limits; however, Popper countered that quantum mechanics was a theory susceptible towards refinement and transformation. Thus, the limits and restrictions given by the theory were tentative; through error-elimination (see Chapter One), all theories are overturned. However, Popper thought the claim of completeness presented a serious problem since it implied a finality that could inhibit the creation of alternative theories, and subsequently inhibit scientific progress. With the Copenhagen Interpretation's claim that "true understanding was impossible" (due to irrevocable conceptual limitations and paradoxes) combined with the "completeness," Popper thought a conceptual inertia would impede theoretical physics. He consequently classified this situation as a major crisis within the most successful science. He remarked,

> In my view, the crisis is essentially due to two things: (a) the intrusion of the subject into physics; and, (b) the victory of the idea that quantum theory has reached complete and final truth.[26]

Popper then believed that completeness threatened modern physics as significantly as observer-laden postivism. Popper thought that this impasse paralleled the 19th century dream of the completion of classical physics.

> The Copenhagen Interpretation--or, more precisely, the view of the status of quantum mechanics which Bohr and Heisenberg defended--was, quite simply, that quantum mechanics was the last, the final, the never-to-be-surpassed revolution in physics; together with the thesis that the truth about the situation in physics can be established by arguments based upon physics itself: more precisely, upon Heisenberg's relations of uncertainty or indeterminacy. These were claimed to show that physics has reached the end of the road; that a further breakthrough is no longer possible, although, . . . much is still to be done by elaboration and application of the new quantum mechanics: in other words, by way of "normal science," as distinct from revolutionary science.[27]

Despite probable disagreement with Popper's characterization, members of the Copenhagen school were convinced that certain limits of measurement had been reached. These limits came from (at least) three sources: (i) the Uncertainty relations, which established an insurmountable inexactness, (ii) the discovery of randomness and the indeterminacy of atomic processes, and (iii) the disturbance of atomic phenomena during observation. This onslaught upon the classical tradition of precision and exactitude convinced Heisenberg that atomic knowledge had reached an end in certain respects. For example, he thought that the Uncertainty relations would prevent a comprehension of the nucleus; e.g., nuclear stability and internal (nuclear) energy levels may never be understood.[28]

Bohr's belief in the completeness of quantum theory arose from conceptual issues, along with these empirical considerations. He felt that clear, conceptual understanding was possible with classical physics, but that phenomena within the atomic domain posed theoretical impasses. As Popper summarized,

> When [Bohr] accepted quantum mechanics as the end of the road, it was partly in despair: only classical physics was understandable [and] was [the only] description of reality. Quantum mechanics was not a description of reality. Such a

> description was impossible to achieve in the atomic region; apparently because no such reality existed: the understandable reality ended where classical physics ended. The nearest to an understanding of atoms was his own principle of complementarity.
>
> This principle told us something about the limits of classical physics and thus of understanding. We could understand classical particles and we could understand classical waves and we could understand that the particle description and the wave description were incompatible, . . . yet both [were] necessary. That was the limit to which our understanding could penetrate. It was the end of the road . . . [and] an act of "renunciation" of our understanding was needed.[29]

As we saw in the Popperian critique of Bohr's treatment of concepts, Bohr thought that the complexity of the quantum domain transcended the human conceptual means to explain in nonparadoxical terms. Thus, a mere instrumentalist use of theories was the only available philosophical interpretation.

Before describing the experiment that many realists believed would demonstrate the fallacies of completeness and undercut the empirical basis for nonrealism, a brief review of the empirical details of the completeness issue is first necessary. Although Popper thought that the "correct understanding and interpretation" of these basic empirical facts would resuscitate classical realism, this debate in turn impugned classical and commonsense realism.

Although the Copenhagen perspective suggested that quantum theory was complete, this completeness actually signified an irrevocable incompleteness. That is, certain essential physical descriptions were restricted by quantum theory and considered meaningness in many situations. One such resticted fundamental description was the notion of particle path. This notion was central and often essential in classical physics, and many kinematic and dynamic laws and descriptions

were based upon it. Yet, in quantum theory, this fundamental tool became severly impaired.

First, what is necessary to specify a particle's motion? Only two components are essential: location (position) and velocity (or better, momentum). Classical physics unproblematically determined both components (except within statistical mechanics where literally billions of particles were present; however, sufficient exactitude was attainable with general, statistical descriptions). But interaction with single particles in the atomic domain created fundamental problems. As described in Chapter Two, exact determination of both position and momentum is impossible (in atomic physics). An increasing precision of one value directly leads to a corresponding imprecision of the other value; in other words, since the varience of the components are inversely proportional, an increasing exactness of one value concomitantly involves a decreasing inexactness of the other. This condition, in essence, is the Uncertainty Principle. This relation in principle prohibited the specific determination of these necessary components of path. Heisenberg often implied that the particle _had_ definite place and momentum _before_ measurement, but the observer disturbed it sufficiently to change the original values. Bohr, on the other hand, thought it was meaningless to speculate upon the value before measurement since the conditions of observation could not be separated from the observed. Both agreed that the concept of a particle's path was "metaphysical" since the precise value between observations could never be known. That is, motion along a path signified _continuous_ location and speed. This continuity was impossible

to determine within atomic physics. Observation could locate the particle at various times but the intermittent values were completely unknown. More fundamentally, the conditions of observation imparted energy to the observed particle and perturbed its state (in Heisenberg's description). Decreasing the "probe energy" to diminish the disturbance was insufficient: low energy does not greatly alter the momentum but the particle's location becomes indeterminate. High energy is necessary for exact location but this energy imparts additional momentum. Thus, the precise trajectory of the particle remains in most cases beyond determination.

Many physicists then interpreted the Heisenberg Uncertainty relations positivistically. Since the observed properties could not be clearly demarcated from the conditions of observation, any reference to underlying, "real" states seemed "metaphysical." Heisenberg concluded,

> If we want to describe what happens in an atomic event, we have to realize that the word "happens" can apply to the observation, <u>not to the state of affairs between two observations</u>.[30]

Thus, developments within modern physics seeme to reinforce the view held by logical positivists that reference to a "real world" beyond observation was in fact problematic.

<u>The Specific Critique of Completeness - The EPR Experiment</u>

In <u>The Logic of Scientific Discovery</u>, Popper proposed a thought experiment that attempted (conceptually) to refute the completeness claim by the orthodox view. After careful analysis by several philosophers and scientists, Popper abandoned this experiment and adopted instead the experiment proposed in 1935 by Einstein, Podolsky

and Rosen. The EPR experiment attempted to demonstrate that particle trajectories were not metaphysical and that both position and momentum objectively existed apart from measurement. Although EPR accepted that both values could not simultaneously be determined, they believed that the proposed experiment would demonstrate that the values were not observationally dependent. They emphasized that the problem was quantum theory's incompleteness; the current theory, they argued, failed to give a complete, objective description of existing components of a particle's trajectory. This *gedanken* experiment must now be carefully described, especially since the laboratory results unveiled great surprises and instead impugned classical and commonsense realism.

This experiment was important for (at least) four major reasons: (i) it attempted to prove that quantum theory was incomplete (accordingly, the title of the original EPR article was "Can [the] Quantum Mechanical Description of Physical Reality be Considered Complete?"), (ii) the experiment attempted to show that the observation-oriented positivism was insufficient and a (more) complete description would give a realist account of atomic physics, (iii) the "disturbance of the observed object" problem could be circumvented, and (iv) the experiment would demonstrate general fallacies in the Copenhagen Interpretation (e.g., Bohr's wholeness idea). Thus, EPR concretely challenged vital tenets of the orthodoxy. Both Popper and Einstein thought that the cogent logic and argument of the EPR proposal overtly demonstrated, long before its laboratory testing, the incompleteness and inadequacy of the current theory. What specifically was this experiment?

The EPR experiment primarily sought to demonstrate that both position and momentum measurements are objectively possible. Popper's description of the experiment was clear and concise:

> The [EPR] argument can be regarded as directed against (a) the view that a particle cannot at the same time _have_ a sharp position and momentum and also against (b) the view that _every_ measurement of position must interfere with the particle's momentum, and _vice versa_. [The experiment] proceeds as follows. Suppose one has a composite system described by a Schroedinger equation, containing, say, two particles, A and B, prior to any collision between them. Then they collide; and afterwards one of the particles is measured, which we may call A. We may choose to measure various aspects; for example, we may measure position; or we may measure momentum. If the _position_ of A is measured, this, together with the _psi_-function of the composite system, will allow us to find the _position_ of B. If the _momentum_ of A is measured, one can similarly obtain the _momentum_ of B. As Einstein put it: "Quantum mechanics will then [after measuring A] give us the _psi_-function for the partial system B, and it will give us _various psi-functions [of B] that differ, according to the kind of measurement which we have chosen to carry out upon A_." B may meanwhile have moved as far away as one like-to Sirius, say. In other words, contrary to the original teaching of the Copenhagen Interpretation, one can predict either the position or momentum of B, without in any way interfering with or disturbing B, on the basis of a measurement (and disturbance) of A alone.[31]

The experiment attempted the indirect measurement of a particle without any actual observation of it. Since the combined energy of both particles was known, the state of B could be determined without disturbing it by measuring A. (More specifically, since the sum of the particle's original momentum was known and the individual momentum of particle A was directly measured, the momentum of particle B could then be determined without measurement). The interference and change of the original value of B then was apparently circumvented.

The principle of locality played a crucial role since A was assumed to be autonomous and separate from B after they were sufficiently distant. Popper stated,

> Indeed, B is too far away to be interfered with. Now in EPR it is assumed that there is no action at a distance (an assumption that follows from special relativity), and the EPR argument indeed depends upon this assumption. This assumption was later called "the principle of locality" or "the principle of local action." From the fact that we can, as we wish, obtain the position or the momentum of B without even measuring it directly (one measures only A), Einstein concludes that B must have both position and momentum, and that in either of the two choices--whether a measurement of position is chosen or one of momentum--quantum theory allows us only incomplete information about B. And it cannot be our disturbing B that limits the possible information about B--for we do not disturb B. Measuring (or interfering with) A's momentum may destroy A's position; measuring (or interfering with) A's position may destroy A's momentum. But we cannot be doing that also to B--which may be light years away from A, and thus unaffected by measurements of A (unless of course there is action at a distance--in fact, instantaneous action, faster than the speed of light, for the measurement of A provides us with information about B for the same moment of time as the moment as which have measured A.)[32]

The circumvention of observational interference then was critically linked to the notion of locality. For Popper, the objectivity and autonomy of objects was also linked to locality. Popper concluded,

> According to the locality principle, separated and noninteracting objects are independent. Thus B must have an objective reality apart from any "act of observation," and it must have a sharp position and a sharp momentum at the same time, even though we cannot know both at the same time.[33]

The proposed EPR experiment then attempted to demonstrate that (i) knowledge of the separated and unmeasured particle (B) was independent of direct observation, (ii) both position and momentum values existed autonomously of observation and thus, the principle attributes of the particle had objective reality, (iii) quantum theory presently was incomplete since it denied these facts, and (iv) the "disturbance during

measurement" problem and its positivistic conclusion could be circumvented. One particle (A) was unquestionably disturbed while specifying either position or momentum; however, after determining one value (e.g., the position) of A, a precise and undisturbed value (of the same component, position) of B could be attained. Since a simple choice (of either position or momentum) existed, both undisturbed values of B objectively existed. The orthodox view held that only one, disturbed value was possible. Thus, the orthodoxy apparently had prematurely claimed "completeness."

The Conceptual Framework of the EPR Experiment

Popper and Einstein rested their philosophic and scientific arguments against quantum theory's completeness upon the EPR experiment. Their argument utilized two major concepts: the notion of locality and the notion of definite atomic states independent of observation. Before discussing the philosophical role of these concepts in Popper's argument, a brief summary of the Copenhagen Interpretation, in relation to classical realist views, is beneficial. Paul Davies epitomized the realist-positivist debate:

> The Bohr-Einstein debate is not just one of detail. It concerns the entire conceptual structure of science's most successful theory. At the heart of the subject lies the bald question: is an atom a thing, or just an abstract construct of imagination useful for explaining a wide range of observations? If an atom really exists as an independent entity, then at the very least, it should have a location and a definite motion. But the quantum theory denies this. It says that you can have one or the other but not both.
>
> This is the . . . uncertainty principle of Heisenberg. It says . . . the very concept of an atom with a definite location and motion is meaningless. . . . Position and . . . momentum form two mutually incompatible aspects of reality for the microscopic particle. But what right have we to say that

> an atom is a thing if it isn't located somewhere, or else has no meaningful motion?
> According to Bohr, the fuzzy and nebulous world of the atom only sharpens into concrete reality when an observation is made. In the absence of an observation, the atom is a ghost.[34]

Thus, the Copenhagen Interpretation held that atomic states must be observed to be real. Popper and Einstein argued, on the contrary, that the Copenhagen view and the notion of an autonomous, objective reality were incompatible. (For example, Heisenberg's claim that "objective reality has evaporated" apparently supported Popper's contention.[35]) In fact, Popper claimed that this notion of physical reality dependent upon the observation is a form of subjectivism.

More precisely, "objective reality" implied for Popper that nature exists in an autonomous, definite state. If nature becomes definite by observation, such as postulated by quantum theory for certain atomic states, then science could never be truly realistic. (Physically, quantum mechanics describes a particle possessing "characteristic" states or "eigenstates." The particle is considered to be in an indefinite combination or superposition of these states until observation or some interaction with a macroscopic system; with observation, the particle assumes one definite state. This is called the Projection Postulate; see Chapter Two.) Einstein nevertheless argued that the EPR proposal suggests that definite, measurable properties exist independently of observation and measurement. Quantum theory is incomplete at this point, since observation can measure only some necessary aspects. Einstein did not deny that observation (of a particle) yields only one definite value. The EPR "paradox" proposed

that both necessary values exist which together comprise a definite, objective, autonomous particle. Accordingly, Einstein concluded,

> I am therefore inclined to believe that the description of quantum mechanics . . . has to be regarded as an incomplete and indirect description of reality, to be replaced at some late date by a more complete and direct one.[36]

In addition to the notion of atomic systems that exist in definite states independently of measurement, Popper thought that commonsense realism required locality. In addition to the "deficiency" of quantum theory in omitting a more complete description, the central paradox shown by the EPR argument was the apparent violation of locality. More precisely, as Pagels succinctly summarized,

> . . . the EPR argument shows that quantum theory violated local causality . . . [i.e.,] that distant events could instanteously influence local objects without any mediation.[37]

In classical physics, the central forces (i.e., gravitational and electromagnetic) operate inversely proportional to the distance between particles; in short, the forces of interaction between particles diminish with increasing distance. Popper extended this fundamental axiom beyond physics proper and claimed that biology, history and all scientific, causal investigation implicitly requires the notion that distant events have a negligible effect on local events. Popper's discussions of locality almost granted this notion an <u>a priori</u>, necessary concept of rationality.

Philosophically, the problem of locality is quite complicated. Its precise relationship with realism is ambiguous. Einstein also thought that realism presupposed not only that objects are independent from the

conditions of observation but also that objects are independent from one another after sufficiently separation. Einstein claimed,

> If one asks what, irrespective of quantum mechanics, is characteristic of the world of ideas of physics, one is first of all struck by the following: the concepts of physics relate to a real, outside world. . . . It is further characteristic of these physical objects that they are thought of as arranged in a space-time continuum. As essential aspect of this arrangement of things in physics is that they lay claim, at a certain time, to an existence independent of one another, provided these objects "are situated in different parts of space."[38]

Popper and Einstein's conclusions used basic disjunctive arguments: either quantum theory is incomplete or locality does not hold. Both were convinced that locality must hold, since commonsense demands it. Ergo, quantum theory is incomplete. The issue of locality then played a significant role in the attack upon quantum theory's "completeness" and its nonrealism. Popper was convinced that the test's verification of locality was inevitable since scientific reasoning is founded upon this premise. He said,

> In any case, the main thing that I want to say--and that, as I believe, Einstein wanted to say--is this. The normal way in which things happen in this world is in accordance with local action. . . . If we are to accept action at a distance, we should have to allow for an abnormal as well as a normal way for things to happen in the world. That would be a major blow against common sense. But all our commonsense ideas, including this one, should always be open to criticism.
>
> Moreover, it is not just common sense that conflicts . . . with the rejection of locality. Everything that we know from astronomy and from the technical success of physics also conflicts with [the rejection]: they all suggest the reality of time and the exclusion of action at a distance. Even more important, the idealistic consequences--especially, the theory that the flow of time is a subjective delusion--that are being drawn from [the rejection of locality] and from the whole situation in atomic physics seems to me to conflict very significantly with biology and the theory of evolution.[39]

Popper thus viewed Bohr's "experimental-unity" notion as more than a positivistic deviation; it involved an "absurd" nonlocal unification that clashed with a fundamental premise of rationality.

In the next chapter, I will discuss the recent testing and results of the EPR experiment and their implications for Popper's commonsense realism. In short, the experiments upheld quantum theory and apparently violated the principle of classical locality and also supported Bohr's wholeness concept of experimental unity. Popper was shocked at the results:

> I must admit that these [EPR] tests results have surprised me. . . . I expected that their results would refute quantum theory. But my expectation appears to have been mistaken, since the majority of the tests have gone the other way.[40]

Although most atomic physicists have supported the Copenhagen Interpretation, nearly all were surprised nevertheless with the apparent violation of locality. Despite the surprise and novelty, there is almost unamimous agreement that the Copenhagen Interpretation was strengthened by these experiments, even though the original intentions sought a refutation of the orthodox view. While Popper thought that the nonrealism of the Copenhagen Interpretation was cogently falsified by the EPR thought experiment, the actual results in fact have raised problems with the premises and constraints of commonsense realism.

Popper's Alternative to Complementarity - The Propensity Theory

Before evaluating Popper's commonsense realism, and his specific realist proposals and interpretations of modern science, I will first briefly describe his alternative theory, the propensity theory. Popper thought his theory would give an objectivist and realist account of the

formalism and principles of quantum mechanics. More precisely, propensity theory would remove (i) the nonrealist account of probability and indeterminism, (ii) the nebuluous, "ad hoc" Principle of Complementarity with its particle-wave duality, (iii) the problem of observation and measurement, along with Heisenburg's uncertainty limits and disturbance principle, and (iv) the general positivist interpretation of atomic physics. Popper felt that the propensity theory demonstrated the similarity between classical statistical mechanics and quantum mechanics. Unfortunately, Popper's theory must remain slightly vague in my discussion since its physical and mathematical relationships can only be described here generally.

The propensity theory was not intended to replace or correct quantum theory but rather to simply "reorganize the formalism" by emphasising various statistical laws and principles that could transform the theory's interpretation. For example, Heisenberg's Uncertainty principle and its orthodox interpretation would be subordinated by the propensity theory to more fundamental statistical laws.

The propensity theory was been largely ignored since most physicists do not consider the Copenhagen Interpretation problematic and they do not think that the theory offers substantially new physical insight or content. For example, Heisenberg dismissed the propensity theory as a restatement and affirmation of the current formalism. Popper responded,

> He really thinks that [the propensity interpretation] is the same as the old complementarity view, and thus falls back upon his old doctrine of the perfect duality of particles and waves, of quantum jumps (for which the reduction of wave

> packets is taken as an example), the role of the observer, and all those other orthodox ghosts whose exorcism is one of the minor results of the propensity interpretation, if fully understood.[41] (emphasis added)

Popper countered that the propensity interpretation "takes the mystery out of quantum theory"[42] by demonstrating that quantum mechanics is essentially similar to classical statistical mechanics. Popper thought the theory gives an objectivist account of probability and measurement in quantum theory and that its statistical character is isomorphic to other physical statistical theories.

Popper's six theses on propensity theory were:

> (1) The solution of the problem of interpreting probability theory is fundamental for the interpretation of quantum theory; for quantum theory is a probability theory.
> (2) The idea of a statistical interpretation is correct, but is lacking in clarity.
> (3) As a consequence of this lack of clarity, the usual interpretation of probability in physics oscillates between two extremes: an objective purely statistical interpretation and a subjective interpretation in terms of our incomplete knowledge, or of the available information.
> (4) In the orthodox Copenhagen Interpretation of quantum theory we find the same oscillation between an objective and a subjective interpretation: the famous intrusion of the observer into physics.
> (5) As opposed to all this, a revived or reformed statistical interpretation is . . . proposed. It is called the propensity interpretation of probability.
> (6) The propensity interpretation is a purely objective interpretation. It eliminates the oscillations between subjective and objective interpretation, and with it the intrusion of the subject into physics.[43]

Propensity theory, Popper claimed, could remove subjectivism, observer disturbance, complementarity, and in general, the Copenhagen Interpretation and establish a completely objective probability interpretation. More importantly, propensity theory was also a realistic theory in contrast to the orthodoxy's instrumentalism. Popper stressed that:

> . . . the propensities are not only as objective as the experimental arrangements but [are] also <u>physically real</u> . . .[44]

He claimed that propensity theory would "bridge the gap between . . . the statistical character of modern physics and . . . an objective physical reality."[45] Propensity thus would not only correct the faulty statistical interpretation but would serve as a guide beyond nonrealist and especially subjectivist views of quantum theory.

Popper used "subjectivism" in two different ways within his propensity analysis. One form of subjectivism is the belief that the subject's lack of knowledge (i.e., the lack of having a more, complete theory) creates probabilistic theories. If the observer knew the physical domain more thoroughly, <u>statistical theories</u> would be replaced by <u>exact theories</u>. The other form of subjectivism concerns the observer's <u>physical</u> intrusion and disturbance of the atomic domain. This form relates to the Heisenberg disturbance ("energy exchange") problem.

Preceding the propensity theory were two standard interpretations of quantum theory's statistical character. Popper argued that both of these interpretations were inadequate. First, the subjective interpretation blamed quantum theory's mere statistical nature upon the scientist's incomplete knowledge. Second, the <u>objective</u> interpretation was the frequency theory. This second interpretation is perhaps aptly described in contrast to the propensity theory. Simply put, the frequency theory emphasizes the numerical probability of an event occurring within a sequence of events. A primitive example of this is the one-sixth probability of rolling a '5' on a die. The repetition of

an event in an identical sequence is necessary for the derivation of accurate probabilities. Propensity theory, in contrast, considers the entire conditions under which the sequence is produced. Popper argued that the frequencies do not simply give the probability of an element (a die) in a particular event (a '5'); instead, frequencies depend on the entire experimental arrangement. The frequencies give the tendencies, propensities or dispositions of the propensities of the entire arrangement.

How specifically does this notion differ from the frequency theory? Consider Popper's example of a loaded die. If the frequency of rolling a '5' on this die was one-fourth, the frequency theory would interpret this as a property of the element (the die *per se*). However, Popper argued that the '5' actually resulted from the entire experimental situation and not simply form the die.

> . . . the propensity 1/4 is not a property of our loaded die. This can be seen at once if we consider that in a very weak gravitational field, the load will have little effect--the propensity of throwing a 6 may decrease from 1/4 to nearly 1/6. In a strong gravitational field, the load will be more effective and the same die will exhibit a propensity of 1/3 or 1/2. The tendency or disposition or propensity is therefore . . . a relational property of the experimental set-up. . . . The propensity distribution attributes weights to all possible results of the experiment.[46]

Another (and even simpler) example is given by tossing a penny on an irregular surface. For instance, if a penny is tossed and lands upon a surface with vertical slits, there will be three possible outcomes: the two sides and the "vertical land." This scenario clearly exhibits that the frequency is determined by the arrangement and not simply by the element (i.e., the penny). Frequency theory would state that the "fifty-fifty" probability of the outcome was a property of the

(symmetrical) penny per se; yet, this simple example shows that outcomes, and their respective frequencies, depend upon the entire arrangement. The orientation of the frequency theory then was too narrow and did not properly consider all of the important conditions. Similarly, Popper was convinced that the broader propensity theory could overcome much of the statistical misunderstanding in quantum theory.

Popper argued that propensities and dispositional properties are physically real. The particular statistical outcome of events in the various experimental situations results from the specific arrangements. The statistical character of knowledge originates not from the subject's insufficient information, but from probabilistic conditions themselves. The emphasis should involve the relational, indeterministic situation among the various elements and not the observer's relation to the outcome of an event. For example, using Popper's favorite example of a bagatelle board (pin board) game, the outcome of a ball's movements through a section of the board has certain propensity. If pins are removed, the relation of all pins is new and this relation has unique probabilities.

How specifically does this (purportedly) enlarged probability theory relate to the problem of nonrealism in quantum theory? In contrast to the positivistic emphasis upon observables and their conditions and the subsequent avoidance of real underlying states, Popper believed that the propensity expunged the "observer" from quantum theory. He argued that various and unique statistical outcomes originate from the manipulation of the atomic experimental arrangements per se, rather than upon the observer's immediate disturbance of the

elements. The indeterminacy of atomic events does not arise from the scientist's uncontrolled influences; the conditions themselves are statistical and indeterminate, as in a dice game or a bagatelle board. Popper stated,

> There is <u>nothing</u> peculiar about the role of the <u>observer</u>: he does not come in at all. What "interferes" with the <u>psi</u>-function are only changes of experimental arrangements.[47]

The wave function (or rather, its square of its absolute value) gives the probability of locating a particle in a certain region under certain conditions. When the experimental situation (or the pin-board, or the die) is altered, then its physical description (i.e., the <u>psi</u>-function) changes accordingly. Reference to the observer is not necessary in order to derive the various propensities of the entire arrangement. Popper thought that the objective physical relationships were responsible for the indeterminate, statistical outcomes. Modern physics then could retain the realisma and objectivity of classical physics.

In addition to the eradication of the observer from quantum theory, Popper believed that the propensity theory also abrogated the "sterile" and instrumentalist Principle of Complementarity. Once again, Popper thought that the misunderstanding of the statistical character of quantum theory led to the particle-wave dualism. Although Popper's specific (anti-dualistic) position involves more physics than philosophy and thus cannot be discussed here, it suffices to say that by relating waves to the propensities of particles, the propensity theory avoided the dualism and made particles preeminent. In short, Popper did not believe that an atomic object was "sometimes a wave and sometimes a particle"; instead, waves were merely the statistical distributions or

propensities of particles. Particles were the fundamental "form" for Popper and waves were simply the statistical outcome of many particles. Consequently, the propensity theory denied challenged the view that waves were a fundamental form. Waves for Popper (following Born at this point) were merely the probabilities of locating particles. For example, in the famous two-slit experiment, Popper argued that the eventual interference pattern arose from the propensities of many particles to arrive at various places. More precisely, the wave (i.e., interference) pattern resulted after many particles passed through the slits. Thus, the wave patterns were the propensities of the statistical ensemble of particles. Popper was convinced that no dualism existed: instead, particles were the fundamental condition of matter and they exhibited various propensities, sometimes wavelike and sometimes otherwise. The confusion in the orthodoxy came from the misinterpretation of the statistical tendencies of particles and the statistical character of fundamental quantum laws. (Popper argued that basic laws such as Planck's law, relating energy and photon frequency, and Heisenberg's principle, relating place and momentum, were originally statistical, i.e., many-particle laws.)

In conclusion, Popper presented a multi-faceted project to counter the suspension of classical realism by the Copenhagen Interpretation. His project attacked this interpretation on many fronts, ranging from his propensity theory, the EPR paradox, and his black-box thought experiment to the philosophical analysis of the misuse of concepts and subjectivist probability theory. The restitution and maintenance of realism and objectivity motivated this arduous endeavor. He seriously

believed that the Copenhagen Interpretation corrupted desirable conceptual premises and distinctions (such as a pluralist ontology with its unambiguous dichotomy between the autonomy of the observed and the act of observation). In addition, Popper thought that commonsense realism needed empirical premisses such as locality, the negligible disturbance of the observed and nonduality of particle attributes. Popper's counter-proposals and interpretations have thus revealed the (quasi) a priori constraints of his realism. While realism may indeed be a general metaphysical doctrine not refutable by empirical test, Popper's realism involved numerous empirical premisses and demands upon the conceptual framework of modern science. With Popper's bold conjectures that possess concrete implications, his premisses can now be evaluated to reveal why his project has not succeeded.

Notes

[1] Karl Popper, Quantum Theory and the Schism in Physics (Totawa, New Jersey: Rowan and Littlefield, 1982) 156.

[2] Ibid., 157.

[3] Ibid., 1.

[4] Karl Popper, "Quantum Mechanics without 'the Observer'," Quantum Theory and Reality, ed. Mario Bunge (New York: Springer-Verlag, 1967) 7.

[5] Karl Popper, op. cit., 133.

[6] Ibid., 121.

[7] Karl Popper, "Quantum Mechanics without 'the Observer'," 10.

[8] Ibid., 12.

[9] Ibid., 14.

[10] Karl Popper, Conjectures and Refutations (New York: Harper & Row, 1965) 100.

[11] Karl Popper, "Quantum Mechanics without 'the Observer'," 17.

[12] Ibid., 15.

[13] Alvin Hudson and Rex Nelson, University Physics (New York: Harcourt Brace Jovanovich, Inc.) 912.

[14] Karl Popper, "Quantum Mechanics without 'the Observer'," 14.

[15] Karl Popper, The Logic of Scientific Discovery (New York: Harper and Row, 1968) 222.

[16] Karl Popper, "Quantum Mechanics without 'the Observer'," 17.

[17] Ibid., 17.

[18] Ibid., 20.

[19] Ibid., 22.

[20] Karl Popper, Quantum Theory and the Schism in Physics, 144.

[21] Karl Popper, The Logic of Scientific Discovery, 223.

[22] Ibid., 228.

[23] Ibid., 248.

[24] Karl Popper, Quantum Theory and the Schism in Physics, 98

[25] Ibid., 99.

[26] Ibid., 1.

[27] Ibid., 6.

[28] Ibid., 7.

29 Ibid., 10.

[30] Werner Heisenberg, quoted in French and Taylor, Introduction to Quantum Physics (Cambridge: M.I.T. Press, 1978) 248.

[31] Karl Popper, Quantum Theory and the Schism in Physics, 18.

[32] Ibid., 18.

[33] Ibid., 19.

34 Paul Davies, God and the New Physics (New York: Simon and Schuster, 1983) 102-3.

35 Werner Heisenberg, quoted by Karl Popper in Quantum Theory and the Schism in Physics, 34.

36 Albert Einstein, quoted by Heinz Pagels in The Cosmic Code (New York: Bantam Books, 1982) 138.

37 Ibid., p. 139.

38 Albert Einstein, quoted by Heinz Pagels in The Cosmic Code, 139-40.

39 Karl Popper, Quantum Theory and the Schism in Physics, 26.

40 Ibid., 25.

41 Ibid., 132.

42 Karl Popper, "The Propensity Interpretation of the Calculus of Probabilities and the Quantum Theory," Observation and Interpretation, ed. Stephen Korner (New York: Dover Publications, 1962) 68.

43 Ibid., 65.

44 Ibid., 69.

45 Ibid., 69.

46 Ibid., 68.

47 Ibid., 69.

CHAPTER FOUR

AN EVALUATION OF POPPER'S CRITIQUE OF THE COPENHAGEN INTERPRETATION

In evaluating the premises of Popper's commonsense realism as revealed by his criticisms and counter-proposals against the Copenhagen Interpretation, it is advantageous to first describe the inability of the Popperian project to reinstate classical realism. In his multi-faceted program, his conceptual premises were made transparent and concrete by his specific proposals; hence, his realism is more accessible for evaluation and criticism than purely abstract realist views. It appears that his project revealed constraints overly constrictive and biased against various conceptual and empirical notions such as Bohr's wholeness idea, nonlocality, the complementary attributes of atomic objects and, in general, the nonclassical nature of the quantum domain. Popper was so confident with his premises and views that he thought that the EPR thought-experiment had clearly disproven the positivistic Copenhagen Interpretation.

We will now see how Popper's confidence displayed his adherence to limited classical notions. The actual test results of the recent EPR experiments demonstrates the inadequacy of many commonsense, (quasi) *a priori* philosophical constraints in relation to the empirical domain. In contradistinction, we will also see how David Bohm adovcated a realist interpretation of quantum theory while incorporating many of

Bohr's ideas and contributions. It appears that Popper, on the other hand, misunderstood Bohr's fundamental conceptual views and implications; unfortunately, this misunderstanding was the impetus for Popper's project against the Copenhagen Interpretation. In short, it appears that no actual crisis existed concerning scientific objectivity, despite the suspension of classical realism, and that modern physics is unquestionably progressive.

Review and Results of the EPR tests and their Implications to Popper's Views

Popper supported the EPR tests since he was convinced they would refute the paradoxical and nonrealist Copenhagen Interpretation. The beauty of these experiments was the actual attempt to "test" fundamental conceptual premisses. Two basic premisses of the experiments were realism and locality. Bernard d'Espagnat's definition of realism will be used throughout this chapter.

> Realism [is] . . . the doctrine that regularities in observed phenomena are caused by some physical reality whose existence is independent of human observers.[1]

More explicitly, realists such as Popper and Einstein held that (atomic) physical systems always exist in <u>definite states</u> independently of observation. In contrast, as Heinz Pagels stated, ". . . the essence of the Copenhagen Interpretation is that the world must be actually observed to be objective."[2]

This clash between classical and quantum physics encouraged Einstein to inspect the formalism of quantum theory and to claim that the theory is incomplete; i.e., there are objective elements of physical states, such as both position and momentum of particle trajectories,

that quantum theory cannot sufficiently describe. More importantly, Einstein claimed that quantum theory (implicitly) violates local causality. (Local causality is the thesis that distant objects and events cannot instanteously influence local objects without any physical medium.) The EPR argument then centered on a paradox: either quantum theory is complete and nonlocality holds, or the theory is incomplete and a more complete and objective description is possible. This disjunction was indeed paradoxical since quantum theory was amazingly successful and no empirical inconsistencies suggested an incompleteness; yet, few scientists openly advocated the abandonment of locality. Popper believed that locality was fundamentally crucial for scientific thought and that its renunciation would signify a great stricture upon common sense. Thus, Popper and Einstein's were both confident that the experiments would refute the principal impetus for positivism within modern physics.

The actual EPR tests investigated the direct correlation between two separated and independent particles. Before separation, the particles were united in a "singlet state." This state, simply stated, created a physical correspondence (e.g., "spin") between the particles. The correspondence allowed a simple inference of the particles' values after the separation (e.g., particle A has "up" spin and B has "down" spin). After the separation, and with no further interaction, the particles were assumed to possess independent values. The measurement and disturbance of particle A after significant separation and isolation should be entirely autonomous from the nonlocal particle B. Yet, the experiments revealed a strong, nonclassical correlation between

the measurement (and corresponding value) of A and the concomitant values, however distant, of B. An analogous correlation would be two distinct and isolated coins having interrelated values after many random tosses. If the objects were truly autonomous and the events of coin tossing completely independent, the result should only possess a "50-50" percent correlation. That is, for tosses that yield heads for coin A, coin B should have 50% heads and 50% tails. Yet, the EPR tests, after many trials, suggested a high correlation that would, in this example, "unite" the coins; the value (e.g.,"heads") of one coin might have an 80% correspondence to the value (e.g., "tails") of the other coin. This outcome signifies that the objects are not independent but are unified. (The coin analogy only signifies an uncommon correlation: physically, they were not in any way united into a singlet state.)

In the EPR tests, the random measurement and the corresponding values of particle A had a nonclassical correlation with the values of a nonlocal particle B (that originally was in a singlet state with particle A). The correlation was proved with Bell's Inequality which relates pairs of (spin or polarization) values along pairs of axes of measurement. The inequality holds when the values of one particle are autonomous from the measured values of the other nonlocal particle. The pairs of values are thus correlated to manifest the independence of particle attributes (such as spin or polarization).

Recall that Einstein had criticized quantum theory since it had not granted autonomy to such nonlocal particles but rather had fused them into a single system. Nevertheless, when the tests were finally performed in the mid-1970s by nearly a dozen independent labs, with more

definitive tests recently performed, the results were clearly in support of quantum mechanics. The tests revealed a violation of Bell's Inequality and also upheld the single system, "wholeness" concept. More precisely, the separability of singlet state particles was not proven and more importantly, the autonomy of particle attributes and values from the "conditions" of measurement was not (classically) recovered. Thus, a major impetus for positivist views was enhanced, rather than dispelled. While the EPR proposal had sought to undercut the positivism of the Copenhagen Interpretation, the actual tests in fact cast doubt upon the "local realist" theories.

The EPR proposal originally sought to demonstrate that objects have definite values independent of observation. If truly definite, these values would not be determined by the act of measurement nor by distinct, distant events (e.g., the measurement of another particle). Popper had criticized the Copenhagen Interpretation of quantum theory as a nonrealist theory since it attributed no (or few) inherent properties to objects independently of observation. Bohr's notion of the experimental triad (the observer-apparatus-object unity) was partially responsible for this indefiniteness. Bohr thought that the clear demarcation between (the state of) an object and, for example, the experimental conditions was not attainable. Popper then argued that the EPR tests would reaffirm the traditional clarity and definitiveness. By maintaining an atomic object's independence (from the act of observation) and definiteness, Popper was convinced that the physical positivism of the Copenhagen position would weaken.

What then does the experimental failure of the EPR proposal imply philosophically? While the precise implications are not clear, it appears that at least one of the classical conceptual premises is problematic. That is, <u>either</u> classical realism remains suspended and its premise that objects exist in a definite state independently of observation, <u>or</u>, nonlocality holds and the paradoxical concept of wholeness remains, providing unity to distant objects. Neither option is considered desirable by classical standards. The inhibition of (classical) realism was truly the Popperian nightmare. Some scientists also have found the abdication of realism an unpleasant alternative. After assessing the implications of the EPR failure, d'Espagnat remarked,

> The sense of paradox induced by the finding that the Bell Inequality [or, simply put, locality] is violated can certainly be alleviated by adopting a positivist attitude. . . . When all the consequences of abandoning realism are considered, however, it is too great a renunciation to have much appeal. In the context of this experiment positivism asserts that it would be meaningless to attribute anything resembling a definite spin component to a particle <u>before</u> the component is <u>measured</u>; that the only quantity with any verifiable reality is the observation itself, the sensory impression; and that the [scientist's] demand for an objective explanation of the remarkable correlation he observes should ultimately be rejected. If <u>this refusal to seek underlying causes of observed regularities is applied consistently, it trivializes the entire scientific enterprise. Science is reduced to a set of recipes for predicting future observations from a knowledge of past ones</u>. Any notion of science as "the study of nature" is impossible; nature is a phantom. One can imagine a physics grounded on positivist principles that would predict all possible correlations of events and still leave the world totally incomprehensible. Given the extreme consequences of abolishing realism, one is inclined to cling to [this] first premise.[2] (added emphasis)

The rejection of realism obviously was not an easy nor desirable abdication for this physicist; otherwise, science would essentially be

trivialized. Before Bohr and Mach, most physicists have held that science has ontologically surpassed the level of "mere recipes" and that science sought to explain true relationships and causes.

In addition, the rejection of locality is as difficult as the renunciation of realism. Popper often emphasized that locality was intimately bound to common sense and that paradoxes (and even "absurdities") could arise with its abandonment. Consequently, neither premise offered an "easy way out" (with the other's rejection). New nonclassical proposals are now suggested, such as nonlocal realism (in contradistinction to Popper and Einstein's "local realism"). This view proposes that some objects and states are interconnected in a manner beyond classical explanation. For example, both Bohm and d'Espagnat attempted to salvage realism after the EPR tests by constructing nonlocal realist interpretations.

Regardless of the precise philosophical implications, the actual testing of the EPR paradox have strengthened Bohr's views. Whether classical, commonsense realism is suspended or classical locality is restricted, the wholeness concept remains intact. With wholeness, Bohr had resisted attributing properties to objects independent of observation (i.e., avoided realism) <u>and</u> also had advocated the unity of experimental (singlet) states (despite the significant separation of components) and thus implicitly supported a form of nonlocality. Consequently, the observer-apparatus-object triad <u>remains unrefuted</u>.

Further discussion of the philosophical implications upon Popper's commonsense realism by the EPR test results will occur in the next chapter. Nevertheless, in summary, <u>demonstrating the current acceptance</u>

and status of Bohr's ideas, note Paul Davies' description of this situation:

> Quantum theory suggests that, at least before an observation is made, the system of interest cannot be regarded as a collection of things but as an indivisible, unified whole. Thus, the two distant polarizers and their respective photons are not actually two isolated systems with independent properties, but linked enigmatically through the quantum processes. Only after the observation is made can the distant photon be regarded as acquiring a separate identity and an independent existence. Moverover, . . . it is meaningless to assign properties to a subatomic system in the absence of a precise experimental arrangement. We cannot say that a photon "really" had such-and-such a polarization before measurement. It is therefore incorrect to regard the polarization of a photon as a property of the photon itself; rather, it is an attribute which must be assigned to both the photon and the macroscopic experimental arrangement. It follows that the microworld only has properties by sharing them with the macroworld of our experience.[3]

Despite Popper's confidence that the "problematic" Copenhagen Interpretation would be refuted and surpassed, Davies' description signifies the persistence and strength of Bohr's concepts and his challenge to classical realism. Since the attributes and values of atomic states can not often be considered as independent from the conditions and process of measurement, Popper's basic premise concerning the autonomy of "first-world" objects is problematic. Consequently, it is Popper's realism, and not the Copenhagen Interpretation, that is currently questioned.

An Evaluation of Propensity Theory

Popper firmly believed that the propensity interpretation would "exorcise the observer and take the mystery out of quantum theory." More importantly, the propensity theory could resurrect realism by showing that propensities describe real, objective processes and are not

simply instrumental result of experimental manipulations. For example, instead of the complete attribution of wave and particle phenomena to the observational conditions that produced them, propensity theory proposed that these phenomena were not "mere observables" and could be considered real and objective.

Paul Feyerabend presented a detailed critique of Popper's theory that subordinated the proposal to its adversary:

> . . . Popper's criticisms and his alternative proposals once more reveal the strong points of the Copenhagen philosophy, and especially the ideas of Niels Bohr.[4]

Feyerabend's view of propensity could be summarized by the title of a section in his "Complementarity" paper: "Propensity, a part of Complementarity." That is, Popper's valid points affirm, not refute, parts of Complementarity, though Feyerabend felt that much of the other parts of Popper's argument were irrelevant. Propensity lacked the breadth and fertility of Complementarity, and thus was at best only an affirmation of its strength. In fact, Popper's propensity theory paralleled key themes in Bohr's Principle of Complementarity. Feyerabend remarked,

> This parallelism is rather striking for it makes Popper stand much closer to Bohr whom he attacks than to Einstein whom he defends.[5]

The propensity theory (Chapter Three) had emphasized the statistical tendency of the overall experimental arrangement. For example, the probability of a particular outcome (a '5') should not be considered as a property of the die per se but rather of the die-plus-surroundings. A loaded die in the presence of a magnetic field will have a different propensity than without the magnetic field. The

overall experimental situation then has varying tendencies, depending upon the specific overall arrangements. Feyerabend emphasized that Popper's description here strongly paralleled Bohr's wholeness notion. Popper's dice-plus-surroundings idea constituted a "single indivisible block";[6] this indivisible block closely imitated Bohr's wholeness idea.

In the propensity theory, properties are not to be attributed to specific objects per se but to the overall relationships of, for example, the loaded die, smooth table and strong magnetic field. Popper stated,

> Propensities are properties of neither particles, nor photons, nor pennies. They are properties of repeatable experimental arrangements.[7]

This idea signified that phenomena cannot always be subdivided; it is often impossible to sharply separate the behavior of an object per se from its interaction with other objects and with the physical set-up (e.g., the experimental apparatus, the pins on the pinboard, etc.). Thus, a phenomenon for Popper does not necessarily concern an individual object but rather the interrelationship of objects and conditions. Compare this view to Bohr's definition of a phenomenon:

> . . . phenomenon exclusively . . . refers to . . . observations obtained under specified circumstances, including an account of the whole experimental arrangement.[8] (emphasis added)

Thus, Popper's idea of the die-plus-surroundings closely paralleled Bohr's indivisible "block" analysis.

Popper called the Copenhagen's Interpretation's misuse of quantum mechanics' statistical theories the "Great Quantum Muddle." The orthodoxy had treated the distribution function (i.e., the mathematical representation of propensities) as the physical property of the elements

(e.g., particles, dice, pennies) per se, rather than the relational property of the experimental set-up. For example, the orthodoxy suggested that wave phenomena resulted from the object's possession of wave properties. The same object, in other circumstances, exhibited corpuscular phenomena, and it was suggested that the object also possessed particle properties. Many scientists concluded that a complementary situation existed, i.e., the object has both wave and particle properties. Popper argued that such complementarity was a muddle: the object itself does not possess particle and wave attributes but such phenomena result from the experimental arrangements themselves.

In Chapter Three, it was mentioned that Popper denied that waves were the "fundamental form" of matter but rather were the propensity and disposition of certain experimental arrangements. That is, some arrangements "elicit" wave phenomena (e.g., interference patterns in the multi-slit set-ups) whereas others do not. Such phenomena do not originate from the object's attributes but from the make-up of the physical conditions. Accordingly, Popper called propensities:

> abstract, . . . relational facts, not attributable to any planet [or particle] or to any point in space, but a relational property of the whole solar system [or atomic arrangement].[9]

Popper then blamed the Complementarity notion upon the false attribution of experimental phenomena to the objects per se.

Feyerabend strongly disagreed with Popper's characterization of Complementarity. In fact, he argued that Popper's position was similar to Bohr's view. Bohr had avoided the classical attribution definite properties to objects independently of the total observational

arrangement. Bohr's stance was condemned, by Popper and others, because Bohr had "nonrealistically" circumvented the attribution of definite properties to atomic objects. As we saw, this stance motivated the EPR experiments. Thus, Bohr's Complementarity, in general, did not emerge from the dualistic attribution of opposing properties to an object. More precisely, Bohr claimed, like Popper, that experimental conditions were responsible for wave or particle phenomena. For example, in explicating Bohr's standpoint, C. Hooker stated,

> Which [particle or wave] concepts are applicable to a given system depends <u>upon the entire physical situation in which the system is located</u>, including in particular, the measuring apparatus involved.[10] (emphasis added)

More directly, Bohr argued,

> Under these [complementary] circumstances, an <u>essential element of ambiguity is involved in ascribing conventional physical attributes to atomic objects</u> . . .[11]

Bohr then had originally avoided the "Quantum Muddle" and remained consistent with his general approach of circumventing objective property attribution. Instead, his wholeness approach attributed any paradoxical processes to the experimental totality. Hence, Popper's propensity theory did not refute nor greatly diverge from Bohr's position.

Feyerabend's overall view of the propensity theory was not generous. He believed that its stronger and relevant points only reaffirmed Bohr's original thesis and that it only offered a fraction of Complementarity's rich <u>physical</u> content. For example, propensity did not incorporate various essential dynamical variables (e.g., momentum, position, etc.) into the working mechanics of the theory.

> . . . propensity takes probabilities out of the individual physical system and attributes them to the experimental arrangement. Complementarity does the same; but in addition

> it also takes position, momentum and all the other dynamical variables out of the individual physical system and attributes them to the experimental arrangement. . . . We shall say that complementarity asserts the relational character not only of probability, but of all dynamical magnitudes.[12]

Feyerabend later added,

> The propensity interpretation says that probabilities change when the conditions change. Period. Complementarity allows us first to see how propensities can be incorporated into the quantum theory . . . and then informs us what properties are related to what conditions and how they change in the presence of forces or of other processes compatible with the conditions of their application.[13]

The propensity interpretation, consequently, has not offered a more prolific nor less "paradoxical" theory than the orthodox interpretation of quantum theory.

Feyerabend was quoted earlier as asserting that "Popper stands much closer to Bohr, whom he attacks, than to Einstein, whom he defends." This claim appears supportable in light of Kurt Hubner's discussion of the Einstein-Bohr debate. Hubner stated,

> I will now try to formulate the philosophical axioms lying at the root of the debate in question in a more generalized form, removed from the specific case under consideration. According to one of these axioms, that underlying Einstein's position, reality consists of substances that have properties which remain unaffected by the relations between substances. According to the other axiom, that of Bohr, reality is essentially a relation between substances and measurement uncovers an intrinsic state: for Bohr a measurement constitutes a reality. For Einstein relations are defined on the basis of substances; for Bohr substances are defined on the basis of relations.[14]

Probably neither Bohr nor Einstein would accept this ontological characterization of their views but Hubner's quote does reflect an essential difference between Einstein and Bohr. Einstein, as a classical realist believed that science (ideally) sought to unveil the essential, true properties of substances. Bohr, on the other hand,

emphasized the relations of objects and the experimental conditions and apparatus without ontological attribution. But Popper's propensity theory was also a relational theory and avoided attributing experimental phenomena to any object per se. Recall Popper's claim that propensities are properties of neither particles, nor photons, nor pennies but rather are the properties of repeatable experimental arrangements. Therefore, Popper's view did not support Einstein's "substance view" and "stood much closer to Bohr whom he attacked."

Bohm on Wholeness and its Implications for Commonsense Realism

David Bohm's views can greatly help to display fundamental characteristics and premises of Popper's realist reinterpretation of modern physics. Bohm is a theoretical physicist who had incorporated much of the counterintuitive content of (the Copenhagen Interpretation of) quantum theory into a realist interpretation. Bohm, unlike Bohr, avoids the instrumental retort that the paradoxical character of quantum theory originates from the limitations of human concepts. Instead, Bohm proposes a realist understanding of quantum theory and, for example, advocates a literal acceptance of nonlocality. In fact, Bohm's latest work, Wholeness and Implicate Order, draws substantially upon Bohr's wholeness notion along with the "violation of classical locality" findings of the EPR tests. The juxtaposition of Bohm's realism with Popper's realism then can delineate key premisses and constraints of Popper's position. More precisely, Bohm's view helps to demonstrate that Popper's dichotomies are not imperative for realism: (i) the nonseparability of objects is not required for realism, (ii) nonlocal

influences are not prohibited, (iii) the separation of the observed from the conditions of observation are not mandatory, and (iv) the denial of complementary attributes, such as particle and wave characteristics, is not required for realism.

Until 1952, Bohm supported the Copenhagen Interpretation of quantum theory. He then proposed an alternative interpretation, the "hidden variables" theory of quantum mechanics. Popper cited Bohm as a respectable theorist who challenged quantum mechanics' orthodox view. Nevertheless, the following passages from Bohm's recent writings reveal how he supported and amalgamated Bohr's ideas into his hidden variable theory.

For example, in support of wholeness, Bohm stated,

> [Bohr] argued that in the quantum domain <u>the procedure by which we analyse classical systems into interacting parts breaks down</u>, for whenever two entities combine to form a single system (even if only for a limited period of time), the process by which they do this is not divisible. <u>We are therefore faced with a breakdown of our customary ideas about the indefinite analysability of each process into various parts, located in definite regions of space and time</u>. Only in the classical limit . . . can the effects of this indivisibility be neglected; and only there can we correctly apply the customary concepts of <u>detailed analysability of a physical process</u>.[15] (emphasis added)

He later added,

> The classical idea of the separability of the world into distinct but interacting parts is no longer valid or relevant. Rather, we have to regard the universe as an <u>undivided and unbroken whole</u>. Division into particles, or into particles and fields, is only a crude abstraction and approximation. Thus, we come to an order that is radically different from that of Galileo and Newton . . .[16] (original emphasis)

Notice that Bohm's view even superceded Bohr's position in certain respects, since Bohm extended wholeness (i.e., a quantum idea) to the

macroscopic world, whereas Bohr utilized classical concepts in the classical domain.

In the experimental domain, Bohm also embraced a Bohrian approach. The EPR results encouraged his acceptance of the experimental indivisibility. Bohm remarked that:

> . . . the description of the experimental conditions does not drop out as a mere intermediary link of interference, but remains inseparable from the description of what is called the observed object. The "quantum" context thus calls for a new kind of description that does not imply the separability of the "observed object" and "observing instrument." Instead, the form of the experimental condition and the meaning of the experimental results have now to be considered one whole in which analysis into autonomously existent elements is not relevant.[17]

This indivisible unity does not allow analysis of a physical phenomena into major components; the "object's behavior" cannot be differentiated from the instrument's action with the particle.

> To speak of the interaction of "observing instrument" and "observed object" has no meaning.[18]

Bohm again took these ideas further (in some respects) than Bohr, and utilized the "human domain" in stronger terms than Bohr. Bohr was very reluctant to incorporate any cognitive or cultural elements into science or, in specific, into the experimental totality. For Popper, the admixture of any second world processes with objective science was probably the "greatest possible scientific sin." Bohm's notion of wholeness, however, suggested that this additional components were necessary for science. Bohm argued,

> The individual wholeness of modes of observation, instrumentation and the theoretical understanding . . . implies the need to consider a new order of fact, that is, the fact about the way in which modes of theoretical understanding and of observation and instrumentation are related to each other. Until now, we have more or less just taken such a

> relationship for granted, without giving serious attention to the manner in which it arises, very probably because of the belief that the study of the subject belongs to "the history of science" rather than to "science proper." However, it is now being suggested that the consideration of this relationship is essential for adequate understanding of science itself, because the content of the observed fact cannot coherently be regarded as separate from modes of observation and instrumentation and modes of theoretical understanding.[19]

Bohm then entertained "forbidden notions" (by Popper) such as the nonseparability of the observed and the observation and, more dramatically, the totality of the entire observation process including the theoretical and instrumental milieu.

As we will see in the next chapter, views such as Bohm's are very significant in evaluating commonsense realism. Bohm embraced a myriad of uncommonsensical, quantum paradoxes as a realist. He did not retreat to an instrumentalistic and positivistic interpretation to avoid the equation of quantum paradoxes with real processes. Thus, the suspension of realism in quantum mechanics is not requisite; rather, the antagonism concerns particular forms and articulations of realism. More specifically, Popper's commonsense realism and the realism of classical physics is clearly at odds with modern science due to various particular premises. Popper maintained various a priori requirements and constraints for the form and interpretation of an objective, realistic science. In the next chapter, I shall address this critical issue whether successful research programs, such as the Copenhagen Interpretation of quantum theory, should subordinate empirical hypotheses and principles to any a priori concepts that seem necessary for objective, realistic science.

An Unnecessary Exorcism

Popper thought that by annulling all substantial references to the manipulations, effects and decisions of the observer, modern science would regain objectivity. Yet, he worried that the Copenhagen Interpretation's emphasis upon observables within physical descriptions and the avoidance to the underlying real states signified the abdication of traditional, realistic science. Einstein voiced similar sentiments. Einstein complained,

> What I dislike in [Bohr's] kind of argumentation is the basic positivistic attitude, which from my point of view is untenable, and which seems to me to come to the same thing as Berkeley's principle, "esse est percipi."[20]

D.I. Blockhintsev carried this criticism further and explicitly called Bohr an idealist.

> . . . all problems of quantum theory, according to Neils Bohr, are to be viewed as problems pertaining to the interaction of the instrument and the micro-object, as problems--and with this he abandons the firm footing of physics--of the interaction of subject and object. The fundamental methodological mistake of the theory of complementarity resides in this fact as well: in light of this conception, the laws of quantum mechanics lose their objective character and become . . . laws resulting from the manner and meaning in which man perceives the appearance of the microworld. And this is idealism.[21]

Are these characterizations of Bohr's philosophy actually accurate? Did Bohr create a "ghost" that later needed an exorcism to maintain scientific objectivity? Was Popper's immense fear of the observer (and consciousness) a legitimate concern?

The orthodoxy's proponents, and some antagonists, have given a resounding "No!" to all three questions. Bohr's critics may have created their own "quantum muddle" by failing to distinguish between two forms of observer "dependence." One form of the observer-observed

relation parallels German idealism's subject-object dualism where the natural world stands in opposition to the subject's "consciousness"; the observer-apparatus-object unity would signify here the dependence of the (atomic) object upon the observer's consciousness. When Popper sought to purge the observer from quantum mechanics, he sought to remove "consciousness." The other form of the observer-observed relation does not require the use of consciousness; the physical effects and disturbances during observation are important but the observer's consciousness apparently has little or no influence upon the atomic domain. (This is the observer-dependence that Bohr advocated and not consciousness-dependence.) The human observer here can perhaps be replaced by a machine that automatically performs the necessary procedures (similarly to Popper's black-box experiment). Bohr's point was that the machine must not be divorced from the atomic object in any objective description. The (whole) phenomenon signifies the "object" and any instruments.

Proponents of the Copenhagen perspective have argued that Bohr's position clearly advocated the later position (i.e., dependence without consciousness) and thus was not an "idealist" view. Likewise, Feyerabend castigated Popper's muddle of this distinction. Feyerabend stated,

> [Bohr's] objective character of . . . explanation . . . does not in any way refer to . . . consciousness. In [Bohr's] earlier papers one hears occasionally of the "impossibility of the distinction . . . between physical phenomena and their observation" but it is quite clear that the term "observation" does not invoke subjective elements but merely refers to the physical "agencies by which [the phenomenon] is observed."[22]

Yet, how does this situational and materialist view cohere with Bohr's belief that the relation between the subject and object was one of the fundamental concerns of atomic physics? Bohr did indeed think that this relation, or "this problem of an observer who is both actor and spectator in the world that surrounds him,"[23] was of crucial new importance; however, he did not accept an idealist or subjectivist conclusion. He avoided any subjective references by continued use of "objective" descriptions of experimental conditions. In short, no references were made to the observer's experiences and subjective impressions (*contra* Berkeley). Instead, all macroscopic results were described in classical language and "explained" by quantum mechanics' formalisms and laws. On the atomic level, there *is* often a difficulty in distinguishing between the attributes of the object from the conditions of observation. However, with the use of classical concepts in describing the experimental conditions and results, the conventional (and classical) distinction between subject and object is (usually) unambiguous and can prevent all subjective references.

Accordingly, Feyerabend argued that Popper's accusation of subjectivism was ill-founded. Feyerabend stated,

> Bohr is interested in the interaction between the subject and the object and he also emphasizes the similarity between physics and psychology in which [the] latter science "we are continually reminded of the difficulty of distinguishing between subject and object. But the "subject" in physics is for him not the consciousness of the observer but "the agency" used for observation, that is, the material measuring instrument (including the body of the observer, and his sense organs); and the "boundary" disappears from between the [atomic] phenomena [and] the [material] agencies of observation." There is therefore no "ghost" to be exorcised from quantum mechanics.[24]

Feyerabend said that Bohr was Kantian in distinguishing between consciousness and natural phenomena. "Nature" is dependent on human forms of perception and categories.

> . . . the difference is that physical interactions involved in any act of cognition are taken into account and that consequences for epistemology are drawn from such physical considerations.[25]

Thus, for Feyerabend, Popper mistook the observer for a "conscious subject" while Bohr avoided this association; instead, Bohr emphasized the physical wholeness or totality of the object(s) investigated, the observed properties and the experimental conditions.

Furthermore, Popper continually interpreted Bohr's observer-observed relation from a perspective that Bohr also criticized. Popper used the classical relations and dichtomies: the observer--influences and disturbs--the object--with the measuring instrument. Popper used this classical epistemological dichotomy to indict Bohr with anti-realism; i.e., the "object" depends upon the "observer" and not primarily upon the real, underlying conditions. On the contrary, Bohr rejected such "interaction" language since an interaction between components implies their separation and autonomy. Hooker stated,

> Bohr has often been badly misunderstood, I believe, because his readers have insisted on reading the classical ontological and epistemological assumptions into these remarks, forgetting his basic doctrines. There is not "disturbance" present here in the classical sense of a change of properties from one as yet unknown value of some autonomously possessed physical magnitude to a distinct value of that magnitude under the causal action of the measuring instrument.[26]

Hooker extended Feyerabend's emphasis upon Bohr's physical indivisible wholeness and added a conceptual dimension. That is, within the atomic domain, it is often not only impossible to physically separate, for

example, the object's properties per se from the measuring instrument; it also cannot be conceptually justified.

> Bohr flatly denied the applicability of the classical notion of "disturbance" of a system and emphasized the "wholeness" of the measuring apparatus-object situation. The two are "indivisibly (=unanalyzably) linked" during the interaction, so that it is impossible in principle to separate the object from the apparatus. The "impossible in principle" here should not be read merely as "physically impossible," but as the much stronger "descriptively, or conceptually incoherent." It is not that some disturbance is incalcuable but that the entire concept of two things, apparatus and object, each having its properties autonomously, is a logically improper analysis of the descriptive process. Descriptively, there is a single situation, no part of which can be abstracted out without running into conflict with other such descriptions.[27]

Popper's thought-experiment with the battery of black boxes was then not directly relevant to the Copenhagen Interpretation. He addressed Walter Heitler's nonrepresentative view about the role of consciousness in quantum mechanics and easily refuted it. Bohr and Heisenberg agreed that the conscious observer was not necessary for experimental observation and that a measuring instrument (similar to Popper's sealed, automatic box) could perform the experiment. Bohr's thesis, however, was that the battery of boxes could not be separated, physically or conceptually, from their respective, internal atomic objects. The nature of the "interaction" (to use Heisenberg's earlier description) prevented a clear demarcation between the instrument and the object due to the "disturbance" and energy exchange. Hence, even within Popper's experiment, the indivisible "unity" of the apparatus-object still prevented a classical demarcation. Popper's experiment essentially "missed the mark" on two counts: (i) Heitler's "conscious observer" was a straw man and a nonrepresentative, inessential interpretation, and (ii) the experiment in no way classically divided

the observed from the observer (i.e., the measuring instruments in the boxes in this case). In fact, Popper's propensity theory is similar here to the (Copenhagen Interpretation of) quantum theory in that the phenomenon includes the entire experimental conditions.

Popper apparently equated "wholeness" with observer-dependence and thus an ambiguous form of subjectivity; this view inappropriately mixed a quantum description with a classical description and analysis (i.e., separation). Any nonnegligible reference to the "act of observation" seemed to evoke a cry of "Subjectivism!" from Popper. He often interchanged the term "positivism" with "subjectivism": e.g., the EPR tests revealed that (atomic) phenomena are paradoxically and inextricably linked to the conditions of observation (i.e., a physicalistic positivism); however, the test results did not suggest any significant role of consciousness (i.e., no subjectivism in the traditional meaning). In fact, Aspect's recent testing of the EPR paradox was structured so that essential decisions (concerning the selection of measurement axes) during the actual measurements were made by computers. Thus, Despite some conceptual parallels between these perspectives, they are not synonymous in atomic physics. (The philosophical analysis of Popper's treatment of positivism will be discussed in the next chapter.)

One of Bohr's primary concerns, pace Popper, was the maintenance of scientific objectivity within quantum mechanics. He realized that the novel, perplexing character of the laws and concepts could threaten the traditional clarity of classical physics. This threat was bypassed by the continued use of classical concepts in quantum mechanical

descriptions; this usage is not unproblematic and led to new laws such as the Principle of Complementarity. But, despite the paradoxes and conceptual barriers, unambiguous descriptions maintained the traditional, nonsubjectivist character of scientific description. Physical descriptions now incorporate the conditions and role of observation. Stating a position that is presently and successfully used, Bohr remarked,

> . . . complementarity does in no way involve a departure from our position as detached observers of nature, but must be regarded as the logical expression of our situation as regards objective description in this field of experience. The recognition that the interaction between the measuring tools and the physical systems under investigation constitutes an integral part of quantum phenomena has not only revealed an unsuspected limitation of the mechanical conception of nature, as characterized by attribution of separate properties to physical systems, but has forced us, in the ordering of experience, to pay proper attention to the conditions of observation.[28]

Bohr directly addressed the "subjectivism" issue and remarked,

> . . . the appropriate widening of our conceptual framework [does not] imply any appeal to the observing subject, which would hinder unambiguous communication of experience.[29]

Quantum mechanics then imitated classical physics' objectivity but was forced to use an expanded form; the observer's role must now be objectively described.

In conclusion, Popper's immense concern over the new emphasis upon the observer and observables and the corresponding suspension of scientific objectivity was apparently unnecessary. Unquestionably, positivism has prevailed over classical realism within modern physics; however, classical subjectivism (with the dependence upon consciousness) has not been responsible for the suspension of realism. The quest for

objectivity has not been abandoned in quantum theory. Accordingly, Y. Freundlich concluded,

> . . . it is observation, not in the subjective sense of taking note of, but in the objective sense of interacting with a measuring instrument, which is and <u>must</u> be accorded a special role in quantum theory. (So that in my view, Popper's stress on the subject-object dichotomy as the basic issue between him and the Copenhagen Interpretation is <u>fundamentally misconceived</u>.)[30] (emphasis added)

Hubner agreed,

> The relation between an instrument and an object is not at all the same as between a subject and object in the sense of idealism. . . . The core of [Bohr's] philosophy is in itself <u>neutral</u> with respect to different standpoints in terms of the classical theory of knowledge, since it does not contain a direct reference to the subject and no statements about the ego can be directly deduced from it.[31]

Popper had failed to distinguish between different ways of reference to the conditions of observation: some ways appealed to the cognitive observer and others addressed the objective acts and conditions of observation (which are physical). As I will propose in the next chapter, Popper's combination and subsequent classification of these different references as "subjectivism" arose from Popper's own problematic concept of realism.

<u>Popper's Problematic Dichotomy Between Theory and Observation</u>

Popper argued that most conceptual problems in quantum theory arose from misinterpretations and misconceptions of the "core theory," rather than the core theory itself. Thus, the Copenhagen Interpretation was solely responsible for nonrealism. For Popper, modern physics' paradoxical discoveries, such as the particle-wave duality, encouraged <u>ad hoc</u> explanations whenever classical explanations failed. For

example, the Popper did not consider that the Principle of Complementarity was an authentic component of quantum theory; rather it was fabricated to bypass the existing anomalies. Rather than correcting existing views and their paradoxes (to erase the duality), the Principle of Complementarity (purportedly) legitimated these paradoxes and problems. Instead of grossly uniting two diverging and opposing modes of description (i.e., wave descriptions and particles descriptions), this duality and antinomy should have led to a better and less paradoxical theory. Popper thus stated,

> . . . the instrumentalist philosophy was used here ad hoc in order to provide an escape for the theory from certain contradictions by which it was threatened. It was used in a defensive mood--to rescue the existing theory; and the principle of complementarity has (I believe for this reason) remained completely sterile within physics. In 27 years it has produced nothing except some philosophical discussions . . .[32]

In contrast to Popper, N.R. Hanson denied that the Copenhagen perspective was a superfluous interpretation arbitrarily grafted onto the core theory. He argued that the formalism of quantum theory logically suggested the orthodox interpretation. For example, Hanson cited Dirac's fundamental work (in the creation of the "core theory") as support for the Copenhagen Interpretation. Dirac claimed that "the Copenhagen Interpretation figured essentially--not as some afterthought appended to his algebra, but basic to every operation within the notation."[33]

Hanson accordingly supported the legitimacy of the Principle of Complementarity. He pointed out that the roots of Complementarity preceded quantum mechanics by one hundred years and that the duality-of-light controversy had existed since Young's challenge to Newton's

corpuscular optical theory. Throughout the 19th century, physicists were convinced that either particles or waves would suffice to explain light phenomena. However, the <u>bold conjecture</u>, contra Popper, came from Bohr's mutual affirmation of the opposing descriptions. Hanson remarked,

> [Complementarity] is the kernal of the Copenhagen Interpretation; . . . [Complementarity was proposed] because nature refused to live up to 19th century's expectations; . . . it is the merit of the Copenhagen school to have boldly adopted it.[34]

Complementarity then developed naturally from the classical background and through developments such as Einstein's <u>photon</u> hypothesis and Davidson and Germer's <u>wave</u> experiments. Popper held that Complementarity was reactionary and repressive, "producing nothing." Hanson countered that the Copenhagen Interpretation's proposals were revolutionary and daring science, <u>par excellance</u>, and displaced a persistent impasse. Although Popper treated complementarity as distinct from the basic theory and its formalism, Hanson pointed out that the <u>formalism itself</u> involved both particle and wave descriptions without any artificial <u>ad hoc</u> maneuvers.

Popper had also argued that the Uncertainty Principle, in addition to Complementarity, was a deviation and misinterpretation of the "core theory." Popper denied that the Uncertainty restrictions were legitimated by quantum mechanics <u>per se</u>. Both Complementarity and the Uncertainty Principle were serious quantum muddles (for Popper) within the Copenhagen "mis-Interpretation."

Hanson again argued that the Uncertainty principle was also an

essential component of the "core theory" and was not an arbitrary supplement. He claimed,

> [The Uncertainty Principle] is not merely a comment on experimental technique [and limits]. The proposition, "To learn anything about a particle we must interact with it," has the same logical force as "Nothing can move faster than light," or "There cannot be a perpetuum mobile.". . . None of these state mere matters of fact. Each involves the conceptual principles of entire physical theories. Similarly: one must interact with microparticles to learn about them. The negation of this, although not self-contradictory, is physically unintelligible.
> This entails what many philosophers persist in being unhappy about--that in particle physics, the data never come to us packed with invariant properties, undistorted by the observing constraint. Data in microphysics can never be less than a compound of the microevent and some macrophysical system. . . . Interaction is the information concept in quantum physics. . . . Anything "beyond" [Heisenberg's limits] is undetectable and unknowable. The alternative to this can scarcely be made intelligible. It is . . . the feature of experimental microphysics that the degree and manner of the perturbation of the system by the detector is in principle incalculable.[35]

For Hanson there was no workable alternative to the Copenhagen Interpretation. Since quantum theory and its orthodox interpretation form a natural unity, Hanson felt that alternative proposals were even more problematic and artificial. "This is not to say that there could not be [another interpretation and understanding of quantum theory]: . . . only that here and now we cannot even say what an alternative would be like."[36] The "best" alternative, the hidden variables theory, has been very problematic and (the experts agree that) its burden was increased by the EPR results. Hanson concluded that the Copenhagen perspective was not superfluous "metaphysics" but was an integral part of quantum theory itself. In fact, Hanson believed that the orthodox theory would not be abandoned until the theory itself was transformed and completely replaced.[37]

Hanson's unrelenting support of the orthodox interpretation was possibly overly enthusiastic as no theory in the history of science has involved such interpretative debate. In fact, many facets of quantum theory are highly counter-intuitive and defy comfortable explanation. Variations of the Copenhagen Interpretation may be created to ease this conceptual strain. Yet, it appears that Hanson's essential points apply to Popper's view as Popper advocated a huge chasm between the theory and its orthodox interpretation. On the contrary, there were many reasons why a positivist interpretation was unavoidable since unobserved variables truly possessed no physical meaning within the theory. As advocated in the next chapter, the philosophical interpretation of a theory must remain sensitive to the empirical content. The condemnation of a highly successful interpretation or theory due to an undesirable positivism is simple dogmatism. Popper's coerced truncation of the theory from the interpretation was entirely motivated by philosophical and not empirical constraints. Yet, highly complicated problems and paradoxes led Niels Bohr and his colleagues to boldly articulate a counter-intuitive interpretation that continues to thrive and withstand criticism.

The Current Usage of Observation in Modern Physics vs. Popper's Classical View

Popper "prophesied" that the Copenhagen Interpretation's notion of observation would either cripple quantum theory's development or would be rejected. Nevertheless, this notion of observation has continued and quantum theory is considered one of the most successful physical theories. While physicists currently discuss the role of observation in

similar terms to Heisenberg and the founders of the theory, few scientists consider the new account of observation, with its suspension of classical realism, an obstacle to scientific progress. To reveal Popper's faulty prophesy, I now will refer to current quantum mechanics' texts.

Popper claimed in the Logic of Scientific Discovery that the Heisenberg relations had erroneously established limits to physical knowledge and he argued that the disturbance of the object by the experimental conditions was truly not at issue. However, current texts describe the disturbance principle in almost identical terms as Heisenberg's original formulation. In the French and Taylor text we find that:

> Repeated measurements on the same particle are ruled out because the act of observation disturbs the system in a way that can neither be neglected nor precisely predicted.[38]

They add,

> . . . quantum systems are typically so small that the process of observing them alters them. . . . These . . . systems are subjected to various observations in which they are unavoidably altered or destroyed.[39]

Popper attempted to dismiss the orthodoxy's positivism primarily on conceptual, a priori grounds. But there are strong empirical reasons why positivism is currently maintained. For example, R. Shankar stated in The Principles of Quantum Mechanics,

> Notice how in quantum theory, measurement, instead of telling us what the system was doing before the measurement, tells us what it is doing just after the measurement.[40]

Quantum theory does not give any specific and deterministic information about an atomic state before measurement; in fact, quantum theory gives compelling evidence that such "unmeasured information" is often

impossible (for quantum states). Consequently, reference to real, underlying states, is naturally avoided within modern physics since definite predictions often are not possible without a direct observation. (See Chapter 2: Classical physics is so exact that the result of a macroscopic system can often be antecedently known without a later observation.) The current positivism then is not a superfluous interpretation given to quantum mechanics. The positivist interpretation of observation occurs "naturally" while such interpretation is avoidable in classical physics. For example, notice how "positivism naturally arises" in this passage from a standard quantum mechanics text.

> The chief difference between a classical ensemble of the type one encounters in, say, classical statistical mechanics, and the quantum ensembles referred to above, is the following: If in a classical ensemble of N particles, N/3 gave a result [lambda 1] and 2N/3 a result [lambda 2], one can think of the ensemble as having [this arrangement] before the measurement. In a quantum ensemble, on the other hand, every particle is assumed to be in the state [omega] prior to measurement [where] every particle is potentially capable of yielding either result [lambda 1] or [lambda 2]. Only after that measurement are a third of them forced into the state [lambda 1] and the rest into [lambda 2].[41]

Popper's insistence that quantum states have definite values independent of observation then simply maintained the classical, traditional notion of measurement. Quantum mechanics gives solid reaons that some atomic states are not in definite states until these systems interact with other systems.

Popper's insistence upon these observationally-independent values was generated by his unrelenting realism. His belief that (atomic) objects have meaningful values independent of observation simply reflects his realism. But the current view holds, on the contrary,

that the belief of observationally-independent values is "metaphysical." Notice the strong empiricist and nonrealist description of measurement and observation in Richard Schlegel's statement:

> In contrast [to classical physics], in quantum physics the occurrence or non-occurence of [property] P for [an individual] x is associated with the observation of P, and there is no meaningful assumption of the occurence (or non-occurence) as independent of the observation and, further, in general no precise theoretical prediction can be made for whether or not a given observation will or will not produce a relevant property P. Hence, the statistical aspect of quantum theory has its base in the dependence of the event on the observation process . . .[42] (added emphasis)

We saw that this view was supported by the EPR tests but the nature of observation in quantum theory took an even more "dramatic turn" at this juncture. That is, the nature of observation within quantum theory involves more than simple classical observation. Observation in many quantum situations leads to the creation (or better, the arrangement) of the observed phenomena. Schlegel described the observation act as follows:

> . . . in quantum physics, the observation process creates the event or property that is the individual datum of statistical description. In a sense, of course, it is trivially true in all of science that it is observation that gives rise to information; but in quantum physics the presumption is forced upon us that the event recorded exists only by virtue of the interaction-observation in which it is discerned. The key place of such a subjectivist element in quantum physics was clearly stated by Bohr.[43]

Popper fought this "radical subjectivist" description of observation, i.e., the "creation" of the observed phenomena. He claimed that this notion annulled the objectivity of the observed and that a physical version of Berkeley's philosophy would emerge. If the classical notion of the independence of objects was not maintained,

Popper thought that the conceptual foundation of objective science would collapse.

Nevertheless, when physicists state that "the act of observation creates the particle," their view is more subtle than Berkeley's idealism. Physicists are not implying that the experimenter literally creates the physical world but that the observation-interaction event helps to shape the "individual datum" or object. Observation alters, disturbs and "creates a particular form" through the interaction of the particle with the apparatus. But no idealism is involved and scientists are not creating the world ex nihilo. As Schlegel mentioned,

> The electron or neutron or proton of our experiment is not [literally] created by our observing it; what is undetermined, until the occurrence of the interaction in which we observe it, is a specific observed property such as where it is or how fast it is moving.[44]

The act of observation then "gives" the particle its particular form. If this notion of observation is a form of subjectivism, it clearly is not the traditional view that objects are products of human consciousness. Schlegel concluded that "it is a subjectivism that is different from what we usually mean to convey by that term in philosophy."[45] The notion of "subjectivism" in quantum theory, if at all appropriate, signifies the inhibition of traditional, classical objectivism and realism.

In summary, Popper's overall approach to the suspension of classical realism and, in specific, the problem of observation in modern physics, revealed his classical premisses and constraints. Leon Rosenfeld, on the contrary, praised the suspension of such classical

views and argued that the transformed role of observation was a valuable advance.

> Certainly [the new physics] puts an emphasis unknown to the outdated materialistic metaphysics of the 19th century on the active role of the observer in defining the phenomena: but in so doing, it brings the whole structure of science nearer to reality, in closer conformity with our real relationship to the external world.[46] (added emphasis)

Thus, the insistence upon the classical world view can impede the understanding the Copenhagen Interpretation's new insights.

Bas van Fraassen concludes that the "limits of observation" issues have been debated too abstractly. He argues that these issues must be approached empirically and not simply by a priori philosophical prejudices.[47] Short of further empirical developments, the Copenhagen view of observation is supportable.

Notes

1 Bernard d'Espagnat, "The Quantum Theory and Reality," Scientific American November 1979: 128.

2 Ibid., 139.

3 Paul Davies, Other Worlds (New York: Simon and Schuster, 1980) 125.

4 Paul Feyerabend, "On a Recent Critique of Complementarity: Part I," Philosophy of Science December 1968:310.

5 Ibid., 311.

6 Ibid., 311.

7 Karl Popper, "Quantum Mechanics without 'the Observer'," Quantum Theory and Reality, ed. Mario Bunge (New York: Springer-Verlag, 1967) 40.

8 Neils Bohr, "Discussions with Einstein," Albert Einstein: Philosopher-Scientist, ed. P.A. Schlipp (New York: Harper and Row, 1959) 237-8.

9 Karl Popper, "Propensity Interpretation of Quantum Theory," Observation and Interpretation, ed. Stephen Korner (New York: Dover Publications, 1962) 69.

10 Clifford Hooker, "The Nature of Quantum Mechanical Reality," Paradigms and Paradoxes, ed. R.G. Colodny (Pittsburgh: University of Pittsburgh Press, 1972) 135.

11 Niels Bohr, op.cit., 210.

12 Paul Feyerabend, op.cit., 321-2.

13 Paul Feyerabend, "On a Recent Critique of Complementarity: Part II," Philosophy of Science March 1969: 101.

14 Kurt Hubner, The Critique of Scientific Reason (Chicago: University of Chicago Press, 1970) 81.

15 David Bohm, Wholeness and Implicate Order, (London: Routledge and Kegan Paul, 1981) 73.

16 Ibid., 125.

17 Ibid., 133.

18 Ibid., 134.

19 Ibid., 144.

20 Albert Einstein, "Reply to Criticisms," Albert Einstein: Philosopher-Scientist, 669.

21 D.I.Blokhintsev, quoted by Kurt Hubner in The Critique of Scientific Reason 76.

22 Paul Feyerabend, op.cit. (Part I) footnote #38, 322.

23 Paul Feyerabend, op.cit. (Part II), 88.

24 Ibid., 92.

25 Ibid., 93.

26 Clifford Hooker, op.cit., 155.

27 Ibid., 156-7.

[28] Neils Bohr, Atomic Theory and Human Knowledge (New York: Wiley and Sons, 1958) 74.

[29] Neils Bohr, quoted by J. Bub in "Review of Popper's Observer," Philosophy of Science December 1968: 427.

[30] Y. Freundlich, "Copenhagenism and Popperism," British Journal of the Philosophy of Science 29 1978: 146.

[31] Kurt Hubner, op.cit., 76-7.

[32] Karl Popper, Conjectures and Refutations (New York: Harper and Row, 1965) 101.

[33] N.R. Hanson, "The Copenhagen Interpretation of Quantum Theory," Philosophy of Science, eds. A. Danto and Morgenbesser (Cleveland: The World Publishing Company, 1960) 454.

[34] Ibid., 452.

[35] Ibid., 457.

[36] N.R. Hanson, "Five Cautions for the Copenhagen Interpretation's Critics," Philosophy of Science 26 (1957): 334.

[37] Ibid., 336.

[38] A.P. French and Edwin Taylor, Introduction to Quantum Physics (New York: W.W. Norton and Inc., 1978) 130.

[39] Ibid., 243.

[40] R. Shankar, The Principles of Quantum Mechanics (New York: Plenum Press) 130.

[41] Ibid., 131.

[42] Richard Schlegel, "Statistical Quantum Mechanics: The Copenhagen Interpretation," Synthese March 1970: 66.

[43] Ibid., 66.

[44] Richard Schlegel, Superposition and Interaction (Chicago: U of Chicago P, 1980) 270.

[45] Ibid., 66.

[46] Leon Rosenfeld, "Misunderstandings about the Foundations of Quantum Theory," Observation and Interpretation ed. Stephan Korner (New York: Dover Publishers, 1962) 43-4.

[47] Bas van Fraassen, "To Save the Phenomena," Scientific Realim, ed. J. Leplin (Berkeley: U of California P, 1984) 256.

CHAPTER FIVE

AN EVALUATION OF POPPER'S COMMONSENSE REALISM

The "Crisis" Without Realism

Popper's belief in a conceptual crisis motivated his project against nonrealism in modern physics. Many philosophers and scientists have also denounced nonrealism since it denies that science refers to real entities and laws. Successful scientific laws then have not been veridical but "essentially leave the world incomprehensible." Roger Trigg shared Popper's fear of "dangerous conceptual attitudes" and, in Reality at Risk, denounced the attraction to subjectivism and idealism by scientists. Trigg also converted the claim that "quantum mechanics has made realism intolerable."[1]

The dislike of nonrealism is also shared by scientists. While Bernard d'Espagnat believes that classical realism must be modified, the total abdication of realism would "trivialize" the scientific enterprise. His argument is a basic disjunction: either realism is necessary for science or else the most successful scientific laws are mere recipes for correlating and predicting phenomena and lack ontological value.

More dramatically, during the formation of quantum theory, Schroedinger decried quantum theory's orthodox interpretation as a violation of scientific rationality. Aage Petersen stated,

> In Schroedinger's opinion, the Copenhagen Interpretation of quantum mechanics violates . . . the axioms underlying an orderly objective world picture. Bohr's view that the quantal formalism is solely a device to produce predictions that are obtained under specified conditions is held to be incompatible with the assumption of comprehensibility. Furthermore, Heisenberg and Bohr's "neo-Machian" interpretation of the indeterminacy relations brings the subject-object relationship out of philosophy into the science of inanimate matter. Thus, it is impossible to retain objectivity even there. Judged on the background of the intellectual tradition, quantum physics appears to be a deviation or even a step backwards.[2]

Schroedinger agreed with Popper that the current philosophy of physics was a genuine crisis. The orthodox interpretation was not merely an incorrect superstructure but conflicted with science rationality.

Popper believed that the realist endeavor to explain real laws and entities was the primary motivation for theoretical development. Without this goal, science would stagnate despite any instrumental success. The crisis then for Popper concerned the progress of science. We must inquire then whether in fact the absence of commonsense realism signifies a crisis. Is the suspension of realism an actual impediment to scientific progress?

Consideration of several definitions of realism can be helpful in attempting an answer. Bas van Fraassen formulates realism as:

> Science aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true.[3]

Similarly, Michael Dummett states,

> Realism I characterize as the belief that statements of a disputed class possess an objective truth, independently of our means of knowing it; they are true or false in virtue of a reality existing independent of use.[4]

Both definitions focus primarily upon the truth of statements or theories in correspondence to an independent "world of facts." (Popper

defined reality as the "world of facts.") Another important component of both definitions is the role of belief. That is, realism can be considered as the belief that statements and theories truthfully correspondence to objective facts. Popper's fear of a scientific crisis then pertains to the suspension of a particular belief. The central question can now be posed as: is the lack of metaphysical belief a serious impediment to scientific progress?

Van Fraassen's definition of constructive empiricism, a form of nonrealism, manifests this essential dimension of belief.

> Science aims to give us theories which are empirically adequate and acceptance of a theory involves belief [only in so far] that it is empirically adequate.[5]

In van Fraassen's view, scientists need not "literally construe" statements and theories; that is, it is not necessary to believe that the world is truly described and explained by theories. Scientists instead aim at theories that "save the phenomena" and thus correlate empirical phenomena. Consequently, van Fraassen demarcates realism from nonrealism primarily by the level of ontological belief, or "how much belief is involved therein."[6]

Popper's project in philosophical physics then can be viewed as an atttempted reformation of the infidelity of nonrealist scientists. Various empirical discoveries encouraged the suspension of classical beliefs which Popper thought were imperative for science. The guiding question can now be more precisely posed: is it an impediment for scientific progress that scientists do not believe (or literally construe) the laws and entities of science?

This question raises a curious issue with Popper's objectivist philosophy. Recall that Popper believed that science is objective and rational since its content is a "third-world" product that transcends "second-world" limitations. The third-world is primarily comprised of statements and conjectures that are independent of subjective experience. Popper's second-world is the subjective realm of beliefs, feelings and other states of consciousness. However, it appears that the purported crisis in modern physics concerned the suspension of a particular belief (a second-world characteristic) rather than an objective, third-world theory or class of statements. Popper thought that instrumentalist attitudes would "cripple" scientific research and progress. Thus, after denouncing the irrelevance of the second-world with the objective, realistic third-world, Popper apparently made scientific progress dependent upon the beliefs and attitudes of scientists. Popper clearly thought that realism is indeed a metaphysical belief and not an empirical or demonstrable theory. For example, Popper claimed,

> I am a realist in two senses of the word. Firstly, I believe in the reality of the physical world. Secondly, I believe that the world of theoretical entities is real.[7] (added emphasis)

Yet, the problem is not that realism must be believed (since it cannot be demonstrated) but rather that Popper made scientific progress dependent upon second-world attitudes. His objectivist philosophy had specifically avoided reference to subjective states and instead concerned only the objective content of statements. Yet, Popper's "crisis claim" concerned the lack of certain beliefs.

This apparent inconsistency does not undermine commonsense realism. Perhaps Popper could modify his second and third-world dichotomy to incorporate "crucial beliefs necessary for objective science." Similarly, Clifford Hooker explicitly described realism as an epistemic attitude. For example, he stated that "the core of the difference between van Fraassen's constructive empiricism and realists concerns what kind of epistemic attitude is rational when scientific theories are concerned."[8] In contrast to Popper, Hooker argued for realism as an important component of scientific subjectivity; i.e., science progresses when scientists realistically believe their theories. While this apparent discrepancy does not refute Popper's realism, the rigid demarcation between Popper's ontological worlds does not clarify the complex relationship between the ontological beliefs of scientists and scientific growth.

Nevertheless, a more fundamental and important problem exists concerning scientific belief. Namely, it appears that the role of realist beliefs is exaggerated and that such conceptual doctrines in fact are superfluous in actual scientific practise. As suggested below, it appears that in the inchoate stage of theory formation, instrumentalist and nonrealist attitudes are common and justifiable. More critically, the lack of a literal construal of a theory at mature and successful stages of a theory is also not uncommon. In contrast, Popper portrayed the lack of realist beliefs as a deviation from normal scientific ideology. Yet, Popper never sufficiently disproved that scientists in fact only aim at empirical adequacy (to merely "save the phenomena"), rather than aiming at literal truths of the world.

Arguments against the necessity of realist beliefs can be directly raised from Popper's pronouncements. For example, while Popper denounced the nonrealist crisis in science, he admitted that realism plays no role in methodology. That is, the nature and structure of proposals and theories (and their subsequent testing) are not effected by realist presuppositions. He stated that "within methodology, we do not have to presuppose metaphysical realism . . . and no help can be derived from it except of an intuitive kind."[9] Popper added that realism is a metaphysical hypothesis and is not demonstrable. However, he thought that realist theories did possess some empirical consequences and thus instrumentalist theories were not completely isomorphic to realist theories.

Nevertheless, Popper never sufficiently clarified the actual role of realism in concrete scientific practise and never proved that scientists aim at ontological, "real truth." Thus, the importance of realism in scientific practise is questionable and the subsequent "crisis claim" then is not convincing. Popper must prove that realism is fact a crucial epistemic attitude for scientific progress and practise. He must clarify the relation between metaphysical beliefs and authentic theoretical stagnation and crisis.

In the guiding question concerning the scientific impairment by nonrealism, there is the implicit standard of scientific progress. If the criteria of progress is utilized to question Popper's call for realism, then his project faces another problem. In contemporary physics, it seems clear that progress has not been impeded with the suspension of realism. In fact, the general relationship between

progress and realist beliefs is a moot issue since the role of realism in scientific practise is unclear. Popper formulated much of his realist account of modern physics and philosophy during the early period of quantum theory and he was convinced that instrumentalism had indeed proved to be detrimental. For example, he thought that the instrumentalistic Principle of Complementarity unnecessarily accepted a problematic, paradoxical dualism merely for prediction and avoided a more satisfying, realist account. Popper then claimed instrumentalism impaired progress and stated that ". . .the instrumentalist philosophy is a creed liable to be used in a defensive mood in an attempt to <u>escape refutations</u>. For an instrument raises no claim to truth and so cannot be falsified."[10]

Yet, the Principle of Complementarity has proved to be a vitally important and successful concept in quantum theory. Other instrumentalist examples given by Popper have also proved to be nondetrimental. Thus, Popper's criticism was patently motivated by a philosophical commitment to realism, rather than by existing empirical problems. More fundamentally, Popper needed to demonstrate the necessity of realist presuppositions and beliefs and show that the empirical consequences are nontrivial. Without demonstrating this necessity, the claim of a crisis is not convincing.

The Desirability of Commonsense Realism

Whereas Popper's discussion of realism centered on the conceptual and scientific need of realist premises and interpretations, an alternative approach concerns the desirability of constraints such as

Popper's commonsense realism. In short, did Popper advocate desirable guidelines and norms for science and philosophy, or, on the contrary, could such constraints impede conceptual progress? For example, Einstein sought to replace quantum theory primarily due to undesirable philosophical presuppositions (such as indeterminism and nonrealism) and not because of empirical deficiencies. If such dissent against the conceptual framework of quantum theory was more widespread, then the theory may not have been successfully developed. Thus, in contradistinction to Popper's view, the conceptual "crisis" would have been due to the rigid allegiance to traditional and limited presuppositions.

A general characteristic of Popper's realism was its noncontextual character. That is, Popper advocated an "incessant realism" where instrumentalist and positivist postulates were considered inadequate regardless of scientific context. Since Popper thought that "the task of science . . .can hardly be understood if we are not realists,"[11] any suspension of realism was undesirable.

However, there are convincing historical reasons to question "incessant realism." Michael Gardner, in "Realism and Instrumentalism in 19th century Atomism," cogently argues that a realist interpretation of empirical postulates and principles is often impossible and meaningless. Gardner explains that instrumentist postulates are commonly utilized in theories (for purposes such as tentative predictions). He argues that the realist-instrumentalist distinction makes sense only within the specific context of a theory and that the unqualified dismissal of either view oversimplifies the actual

historical process of theory construction. He concludes that the existing empirical evidence and theoretical structure will determine whether scientists can interpret a postulate realistically or instrumentally.

Similarly, it appears that successful theories often undergo a "cycle of instrumentalism and realism." That is, in the inchoate phase of theory formulation, scientists are often instrumentalists due to the tentative character of the proposed entities and laws.[12] Realist interpretations usually occur in the latter, more mature phase of the theory after a period of successful utilization and confirmation of the entities. At that point, the specific postulates appear to reflect real processes and entities. For example, the reality of atoms was questioned in the early period of microphysics; nevertheless, these postulated entities possessed strong instrumental value. The discovery of Brownian motion, along with other developments, substantiated the "reality" of atoms and a concomitant realism arose within atomic theory. Within contemporary particle physics, a similar cycle often occurs: the "quark" concept was initially a simple instrumental postulate that aided the explanation of nucleons. Since the postulate now plays a larger role and the entities are utilized more substantially, quarks now are viewed more realistically. When a theory matures and the entities are manipulated and utilized, these entities are considered to be real.[13]

This "instrumentalism-to-realism" cycle suggests that the Copenhagen Interpretation's original positivism was a natural response to the paradoxical discoveries and laws of quantum mechanics (especially in contrast to the more commonsensical classical physics). The

positivist attitude allowed physicists to more flexibly construct the theoretical foundations. Otherwise, scientists would have been impeded by the bizarre nature of the new theory. For example, Hilary Putnam remarked that the reduction of the wave packet (a physical phenomenon unique to quantum mechanics) was only bizarre if the wave was consider to be real. "This reduction of the wave packet constitutes very strange behavior if this is really thought of as a physical [i.e., real] wave."[14] Consequently, the suspension of realism allowed a less-restrictive atmosphere and the theory's development was not inhibited. Despite their own realist views, d'Espagnat and Feyerabend (in his earlier, "realist phase") both agreed that the Copenhagen Interpretation's positivism was of "great help to physicists."[15]

I believe that these examples and arguments support the contention that a rigid and unrelenting realism is not conducive for theoretical development and scientific growth. <u>In essence, Popper's attitude was dogmatic since realism and prolific theories are not always compatible</u>. Popper showed little flexibility and urgently proclaimed that "a very serious situation" had arisen.

Popper believed, on the contrary, that the uncritical positivist attitude of many physicists was dogmatic and highly problematic.

> Today the view of physical science founded by Osiander, Cardinal Bellarmino, and Bishop Berkeley, has won the battle without another shot being fired. Without any further debate over the philosophical issue, without producing any new arguments, the instrumentalist view . . . has became an accepted dogma.[16]

Feyerabend disagreed with Popper's characterization of the struggle within theoretical physics. He argued that physicists such as Bohr,

Einstein, Heisenberg and Schroedinger wrestled with the nonrealist character of quantum theory.

> The realism-instrumentalism issue . . . was one of the most central and most hotly debated topics of the older quantum theory and it was discussed to such an extent that its repercussions should have reached the ears of even a philosopher. Every paper of Bohr's emphasizes that so far an instrument of prediction is all one can have and that this shortcoming is due to the absence of unrefuted hypotheses about the nature of atomic processes.[17]

It appears then Popper oversimplified the process of theoretical construction by demanding an "incessant realism." His treatment of scientific realism used essentially a priori arguments that dismissed instrumentalism on philosophical grounds. Popper overlooked that scientists tend to realistically interpret scientific theories whenever they appear to reflect real processes and suspend such interpretation for empirical considerations. Feyerabend argued that Popper's approach to the realism-instrumentalism debate was empirically insensitive to the specific content of the debate. He remarked,

> . . . the instrumentalism issue in quantum theory is not a purely philosophical affair that can be disputed away by general arguments in favor of realism. The argument "quantum theoretical instrumentalism is a result of positivism; positivism is false; hence, we must interpret the quantum theory in a realistic fashion"--this argument is completely irrelevant and also very misleading. It is misleading because it suggests that a realist can at once interpret the psi-function realistically, and that the reason why it was not so interpreted was only philosophical prejudice. And it is irrelevant because it does not proceed a single step on the way to resolving the physical difficulties which are connected with the realist position in microphysics. A realistic alternative to the idea of complementarity is likely to be successful only if it implies that certain experimental results are not strictly valid.[18]

One may conclude that the general inflexibility of commonsense realism is not desirable. Since coerced realist interpretation

postulates and theories is often not possible, an unqualified anti-instrumentalism is short-sighted. In contrast to Popper's attitude that the absence of realism "would amount to the acceptance of miracles,"[19] theories can often flourish without realist constraints. This point is perhaps illustrated by Feyerabend's parallel discussion of scientific reason. He argued that "without frequent dismissal of reason, [there is] no progress."[20] Feyerabend was not advocating blind irrationalism; he simply illustrated that rigorous science often suspends and even contradicts well-established premises and operations with unestablished, counter-intuitive concepts and techniques. Similarly, the suspension of realism has proved to be "progressive" in modern physics. In fact, without the suspension of classical realism, the development of quantum theory may have been impaired.

The Classical Bias of Popper's Empirical Constraints

Popper's empirical insensitivity to instrumentalism and positivism probably originated from philosophical and scientific norms derived from classical physics. While the specific empirical premises of commonsense realism clashed with quantum theory, they were perfectly compatible with classical physics. Popper's empirical premises were closely linked to more abstract philosophical presuppositions and, as I will argue below, both empirical and philosophical constraints arose from the highly successful classical physics and its conceptual framework. I will conclude then that although Popper proposed a "progressive" use of bold conjectures, his objectivist and realist philosophy of science originated from limited classical premises. This paradox also existed

in his use of commonsense notions: he emphasized the shortcomings of commonsense, intuitive concepts and yet rejected much of modern physics due to its counter-intuitive character.

The limited nature of Popper's specific empirical constraints is unquestionable. Although an indepth empirical evaluation must be handled by physics and not philosophy, it is clear from quantum theory in general and various specific experiments that Popper's presuppositions are unsuitable. For example, Popper's rejection of indefinite states (that become definite during measurement) arose from classical notions. Yet, the Projection Postulate is a successfully utilized and confirmed notion. Popper supported causal indeterminism but denied that atomic states existed in an indefinite superposition and that the observation process could determine the resultant properties.

Popper also denounced the Principle of Complementarity and its idea that matter and radiation could assume two opposing "fundamental forms" (i.e., either particles or waves). He again refused to accept that the experimental conditions were causally responsible for the determination of wave or particle characteristics. His analysis and "solution" of the particle-wave duality were entirely classical.

Another Popperian constraint was the rejection of nonseparibility of atomic states (in singlet conditions). He firmly upheld classical laws where interactions between the components of a system diminished with increasing distance. Consequently, since Popper dismissed nonseparability, nonlocality, indeterminate states and complementarity, he disclaimed Bohr's "revolutionary wholeness concept." He often maintained classical dichotomies and the "analyzability of individual

components" while simultaneously proposing the propensity theory that imitated the wholeness idea.

The EPR thought-experiment most clearly epitomized the classical orientation of Popper's philosophy of physics. His response to the tests manifested his inability to suspend his presuppositions and thus revealed the actual reactionary character of his conceptual framework. Consequently, it appears that the presuppositions of commonsense realism were not only unnecessary but also undesirable. Philosophical constraints and guidelines must arise in conjunction with empirical requirements, rather dictating <u>a priori</u> norms. Otherwise, these philosophical norms can actually impede, and not clarify scientific issues. Similarly, Ernan McMullin's reprimand of Einstein's allegiance to conceptual presuppositions applies to the Popperian constrictions. McMullin's argument is significant since he argues for realism while aware of <u>a danger with rigid premises within realism</u>. McMullin states,

> . . . Einstein's world view included . . . much more than realism; where it failed was not in its realistic component but in the <u>conservative constraints on future inquiry that Einstein felt the success of classical physics warranted</u>.[21] (added emphasis)

Although many philosophers and scientists believe that certain premises within realism are philosophically necessary, they may be considered undesirable and counter-productive from an empirical and historical standpoint. While Einstein remarked that he saw "no metaphysical danger" in his realist beliefs, such constraints could indeed impair the theoretical development of counter-intuitive postulates such as the Principle of Complementarity or the Projection Postulate. McMullin concluded,

> Indeed, it could be argued that worrying about whether or not [specific] constructs approximate the real is more apt to hinder than to help their work as scientists! [22]

Popper's Paradoxical Use of Commonsense and Intuitive Notions

Before assessing Popper's ontological distinctions, another important characteristic of his thought was manifested in his anti-positivist project, viz., his problematic usage of common sense. He supported a critical use of commonsense notions and beliefs although explicitly denouncing many components of quantum theory due to their "irrational" and counter-intuitive character. His reinterpretation of modern physics possessed this tension of supporting bold conjectures while disdaining "noncommonsensical and irrational" proposals.

Popper clearly recognized the insufficiency of commonly used concepts and he explicitly rejected common sense as a "secure starting point" of science and philosophy.[23] New theories and breakthroughs profoundly alter commonsense notions.

> . . . common sense is either modified by corrections or it is transcended and replaced by a theory which may appear to some people for a shorter or longer period of time as being more or less "crazy." If such a theory needs much training to be understood, it may even fail for ever to be absorbed by common sense. Yet even then we can demand that we try to get as close as possible to the ideal: <u>all science, and all philosophy, are enlightened common sense</u>.[24]

The growth of knowledge then builds upon familiar notions and they are transformed by new theories. Science and philosophy become enlightened and improved common sense.

Despite the shortcomings of common sense, the relation between realism and enlightened common sense was significant for Popper. He stated that "[The commonsense view] is the central tenet of what may be

termed 'realism.'"[25] Despite the tenuous nature of commonsense notions, common sense has remained the foundation of science and for realism. Realism in fact received its strongest arguments from common sense. Popper accordingly thought that idealism, subjectivism and scepticism were deviations from sound philosophical common sense. While metaphysical idealism could not be refuted, he nevertheless was convinced that it could be rejected by commonsense arguments.

> But there are arguments in favour of realism; or rather against idealism. . . . Perhaps the strongest argument [for realism] consists . . .[in arguing] that realism is a part of common sense.[26]

Popper concluded that "realism is essential to common sense" and vice versa.

We thus arrive at the key source of tension and paradox in Popper's project. In short, Popper upheld commonsense, classical notions against successful, bold but nonrealistic conjectures. While realism was his general impetus for condemning the Copenhagen Interpretation, the counter-intuitive, nonclassical character of quantum theory was the specific source of distress for Popper. He believed that physicists, with unambiguous commonsense thinking, should reject ". . . those irrationalist symptoms, such as the dream of the quantum theoretical interference of the subject with the object of knowledge."[27] With an adherence to commonsense concepts, the isomorphism of quantum physics to classical physics would become apparent.

The connection between Popper's realism and conservative commonsense notions was clearly demonstrated in his support of the EPR thought-experiment. He was convinced that the empirical basis of nonrealism was refuted by quantum theory's irrational violation of

locality. Thus, either the existing nonrealist theory must be rejected or else a detrimental disruption of common sense would occur.

> The normal way in which things happen in this world is in accordance with local action and thus quite contrary to the apparent outcome of these [EPR] experiments. If we are to accept action at a distance, we should have to allow for the abnormal as well as a normal way for things to happen in the world. That would be a major blow against common sense. But all our commonsense ideas, including this one, should always be open to criticism.
>
> Moreover, it is not just common sense that conflicts with these experiments and with the rejection of locality. Everything that we know from astronomy and from the technical success of physics also conflicts with them: they all suggest the reality of time and the exclusion of action at a distance. Even more important, the idealistic consequences--especially, the theory that the flow of time is a subjective delusion--that are being drawn from these experiments and from the whole situation in atomic physics seem to me to conflict very significantly with biology and with the theory of evolution.[28]

The link between Popper's realism and "normal, rational" notions such as locality was surprisingly tenacious. Even after a dozen independent laboratories had verified the violation of locality, he urged,

> . . . before discarding so intuitively satisfactory a principle as that of local action, the whole situation must be reviewed . . .[29] (added emphasis)

"Intuitive satisfaction" was a central determinant for selecting enlightened commonsense ideas. Popper did not naively accept all confirmed results and would reassess tests and theories on the basis of intuitive satisfaction.

Yet, the EPR tests were exceedingly well-controlled and meticulously analyzed. In light of Popper's general philosophy of science, this denial of a "crucial experiment" was problematic and a serious inconsistency. In short, the Principle of Complementarity,

nonlocality, the Projection Postulate, quantum jumps, and the "irrational intrusion" of the observer into physics, were all rejected on the basis of common sense (and intuitive dissatisfaction), despite substantial empirical evidence.

However, considering the particular character of modern physical concepts and theories, the reliability of intuitive satisfaction and commonsense appeal is highly questionable. Abner Shimony recently remarked that "we live in a strange, 'quantum world' that defies comfortable, commonsense concepts."[30] Similarly, in his quantum mechanics text, J.L. Martin entitled a chapter, devoted to describing the theory's paradoxical character, as "Experience is the enemy of intuition."[31] Martin described how the discoveries and laws of modern physics are often not only counterintuitive but are the "enemies" of intuition and common sense. Bernard d'Espagnat also concluded, after noting the restrictions placed upon common scientific concepts and realism in general, that "perhaps in such a [quantum mechanical] world the concept of an independent existing reality can retain some meaning, but it will be an altered meaning and <u>remote from everyday experience</u>."[32]

This challenge to established successful notions is not unique with quantum theory and probably occurs within all major theoretical transformations. For example, Newton's theory of gravitational attraction was also highly counter-intuitive and was denounced. Huygens thought "action at a distance" was absurd and Leibnitz dismissed the idea as occult.[33] Similarly, Popper dismissed the quantum mechanical

violation of locality as abnormal and that such idea would disrupt necessary concepts and distinctions.

Popper's philosophy of science then was fundamentally paradoxical as he advocated a flexible fallibilism while supporting an intransigent set of presuppositions. Despite Popper's regard for falsifiability and crucial tests, he refused to accept the results of the EPR tests. He claimed that "so far <u>I have not even abandoned locality</u>." [34] (added emphasis) Rather than modify his <u>a priori</u> commitment to commonsense notions, he suggested <u>ad hoc</u> proposals to circumvent the conceptual conclusions of the EPR tests. In fact, although Popper thought that the EPR tests would clearly demonstrate the incompleteness of the Copenhagen Interpretation and its nonrealism, he claimed after the tests that they were not relevant to the debate.

> On the contrary, I think . . . there is not the slightest reason to suppose that realism is affected by these new experiments even if their outcome should show that locality cannot be upheld. Rather, . . ., the consequences, if correct, would go against Einstein's interpretation of the formalism of the Special Theory of Relativity and in favour of Lorentz's interpretation of it and in favour of Newton's 'absolute space.'[35]

After supporting the fallibility of all scientific and philosophical ideas and propositions, Popper unrelenting defence of the tenets of commonsense realism was surprising and dogmatic.

<u>Popper's Classical Ontological Dichotomies</u>

Elements within Popper's philosophical physics can manifest important characteristics of his ontology. For example, while some philosophers have been puzzled with his "third-world" concept, this notion is not strange in light of his philosophy of physics. Popper's

ontological and epistemological distinctions were consistent with his specific empirical distinctions. As we have seen, Popper's empirical constraints originated from classical science. More importantly, his ontological distinctions and concepts also possessed a parallel coherence with classical concepts. Popper apparently derived philosophical standards and norms from classical science that shaped his pluralist realism.

Popper's ideal of objectivity was identical to the objectivity attained within classical physics. He thought that classical physics was entirely objective since the object could be explained and described <u>autonomously</u> from the observer or subject. Popper's standard of objectivity did not demand the object <u>an sich</u> or the object independently of its physical conditions. Instead, science attempts to (partially) describe the <u>real</u> object. Popper utilized objectivity in a traditional sense: the object was not dependent nor resultant upon subjectivity or the observer.

Popper's realism then was consistent with his objectivity critierion: reality is the "world of facts" <u>autonomous</u> from human subjectivity or activity. If the physical world was substantially dependent upon subjectivity, then scientific laws could never approximate the independent truths of the "world of facts." Thus, a fundamental tenet of Popper's realism was the notion of an autonomous realm of entities, conditions and laws.

The concept of autonomy for Popper's ontology, epistemology and philosophy of physics was paramount. His "epistemology without a subject" and his "quantum mechanics without an observer" fundamentally utilized the autonomy of the third-world and the first-world from the

second-world. Epistemologically, the (first-world) physical object is described and explained by nonsubjective (third-world) theories and statements. Since both domains are autonomous from the second-world, philosophy and science need not establish objective knowledge upon subjective experience. Popper stated,

> The idea of <u>autonomy</u> is central to my theory of the third-world; although the third-world is a human product, a human creation, it creates in its turn, as do other animal products, its own <u>domain of autonomy</u>.[36]

Popper argued that the subjective realm was generally not important for science and objective knowledge.

Similarly, Popper's entire project concerning modern physics could be summarized in the phrase: to exorcise the observer from physics. Popper thought that the Copenhagen Interpretation's notion of observation threatened the autonomy of the observed object. Although he did not believe that objects could be divorced from their physical conditions, he vehemently opposed the notion that the properties of (atomic) objects could be inextricably linked to the process of observation. Popper then used the classical notion that the properties of objects were autonomous from any second-world, human contamination.

Popper's third-world was an entirely "depersonalized" realm of statements, theorems, postulates, problems and solutions. These third-world "inmates" existed autonomously from their human creators. The first-world was also ontologically autonomous and nonhuman. Thus, his objectivist epistemology and his philosophy of physics both fundamentally emphasized strict, inviolate dichotomies: physical objects without observers, theories without thinkers and in general, objective knowledge without subjects. His specific philosophy of physics then was

entirely consistent and intertwined with his pluralist ontology. The "ghost" in need of exorcism in quantum mechanics was perhaps the same ghost in subjectivist epistemology.

One may propose then that Popper's realism and pluralist ontology was symptomatic of his desire to maintain classical objectivity and dichotomies. These distinctions were important for classical objectivity and norms. Yet, these distinctions and constraints upheld empirical standards that were unnecessary and undesirable for modern physics. Likewise, his pluralistic ontology proposed philosophical demarcations that did not necessarily clarify epistemological problems; rather, these distinctions were norms to judge and condemn nonobjectivist, nonrealist theories and philosophies. Thus, Popper used his epistemology and philosophical physics primarily to condemn subjectivism and positivism. However, Popper's epistemological constraints may suffer the same shortcomings as his philosophy of physics. That is, classical philosophical and scientific concepts may impede the development of counter-intuitive, progressive theories and ideas.

Popper's rigid ontological distinctions oversimplifed his analysis of nonrealism in science. For example, he exclaimed

> realism [is] the only sensible [metaphysical] hypothesis-- . . . a conjecture to which no sensible alternative has ever been offered. . . . I think I know all the epistemological arguments--they are mainly subjectivist--which have been offered in favour of alternatives to realism, such as positivism, idealism, phenomenalism [and] phenomenology. . .[37]

Since positivism and phenomenology emphasize, respectively, observation and the "primacy of perception," Popper thought that the clear distinction and autonomy of first-world objects from subjective

experience were violated. He subsequently interchanged the terms "positivism" with "subjectivism" and "idealism" since they "are all infected by the subjectivism of the Cartesian starting point."[38]

Popper's equivocation of these views is understandable in light of his epistemological and ontological distinctions. Yet, the equivalence of positivism with idealism or subjectivism was a vast oversimplification of complex problems in contemporary science. While observer-dependence has been a genuine issue in quantum theory, the Copenhagen Interpretation explicitly avoided subjectivism and idealism. Popper's analysis, on the contrary, blurred the subtleties and fused all nonrealist views into subjectivism. For example, he stated in the preface to Quantum Theory and the Schism in Physics:

> . . . Thus arose an idealistic (or even positivistic) philosophy, a philosophy that takes our subjective experiences--especially our perceptions, our observations, as more secure, more certainly real, than the physical reality, which, positivism alleges, is merely our mental construction.[39]

With Popper's rigid dichotomy between pure objectivity and the second-world, any substantial reference to perception, experience, observation or any cognitive factor signified an unqualified subjectivism.

Popper's pluralist ontology, objectivist epistemology and philosophy of physics all suffered from distinctions and standards consistent with classical science but were unsuitable for modern philosophy and science. Whereas Popper's empirical constraints were insensitive to concrete problem situations, his epistemological dichotomies also blurred important nuances between widely divergent views such as positivism and idealism. For example, Popper remarked that "if idealism is true, then anything can happen."[40] While classical

concepts may in fact not be the source of these exaggerated claims, we may still conclude that Popper's ontology and commonsense realism was burdened by distinctions and norms not suitable for epistemological or empirical subtleties.

Beyond Commonsense Realism

In analyzing Popper's commonsense realism, two guiding questions were used: are commonsense realist presuppositions necessary for philosophical comprehension and scientific progress? Are these premises desirable for philosophy and science? It appears that the presuppositions are both unnecessary and undesirable as shown by the success of Popper's adversary, the Copenhagen Interpretation. In fact, this view flourished in spite of these philosophical presuppositions that Einstein and Schroedinger arduously upheld. If their dissent was more widespread, then these presuppositions could have nontrivially impaired quantum theory's development.

However, the inappropriateness of Popper's realism does not undermine realism in general. That is, there are various "forms" of realism are not necessary negated by modern science or by philosophical considerations. In addition, many philosophers find the total abdication of realism undesirable. Since science may genuinely refer to actual entities and laws, nonrealism is often considered undesirable. Consequently, if realism is upheld, what form of realism is desirable or necessary?

While the determination of the necessary components of realism is difficult, various suggestions for premises emerge from the Popper-Bohr

debate. In short, specific presuppositions should not restrict the formation and utilization of counter-intuitive theories. While Popper did not intend to inhibit theories and interpretations, his premises were not in fact compatible with such formulations and were empirical insensitive. On the contrary, realist beliefs and guidelines must be contingent upon historical and empirical developments rather than upon a priori norms biased from former theories. Otherwise, novel theories may be rejected by philosophical and conceptual prejudices instead of empiricial inadequacies.

Accordingly, several contemporary philosophers and scientists explicitly argue for nonclassical realism. David Bohm and Bernard d'Espagnat eskew nonrealist interpretations of physics while addressing the limitations of commonsense, traditional notions. Bohm incorporates many of Bohr's ideas into a realist framework. (In fact, the wholeness concept is pivotal in Bohm's metaphysics.) Unlike Popper, Bohm does not view "the observer" in physics as a threat to science but rather as an enlargement of scientific understanding.

Bernard d'Espagnat denoted classical realism as "near realism." He defined this term as "any vision of the world in which all the elements of reality are supposively adequately described by notions which to us seem near and familiar."[41] Although d'Espagnat defended realism since science would be "trivialized" by positivism, he believed that near realism was seriously vitiated by developments within physics.

> When I say, for example, "the object is real," it would exist at any time, it is in a well-defined position which it would be in even if it were not observed. Or, more correctly, I envision these propositions without making them explicit, since I feel so strongly that they are matter of course. But if I become aware of the fact that I make such assumptions,

> then I discover both a lesson and a warning, for <u>I cannot help but notice that almost unavoidably the concepts that I tend to bring to the level of "elements of reality" are the most familiar concepts (object, position, time). Again, this is the weakness of realism.</u>[42]

D'Espagnat concluded that classical notions such as locality, object separability and independent properties now have new restrictions and thus near realism must be replaced. He subsequently proposed "far realism" or the philosophy of "veiled reality." This view acknowledged that the real properties and structures of the world may never be described by commonsense notions and the best theories may fail to approximate reality.

Ernan McMullin agreed that realism was not terminated by modern physics but simply it commonsense concepts were insufficient.

> Was the Copenhagen Interpretation of quantum mechanics antirealist in its thrust? . . . It would seem not, for Bohr agrees that the world is much more complex than classical physics supposed. . . . He is not holding that from his interpretation of quantum mechanics nothing can be inferred about the entities of which the world is compared; quite the reverse. He is arguing that what can be inferred is entirely at odds with what the classical world view would have led one to expect.[43]

McMillan added that the realist statements of elementary particle physics must be circumspectively interpreted.

> At [the microphysical] level, we have lost many of the familiar bearings (such as individuality, sharp location, and measurement-independent properties) that allow us to anchor the reference of existence claims in such macrotheories as geology or astrophysics.[44]

Thus, the demise of the fundamental concepts of traditional realism need not be seen as the failure of realism in general.

Hilary Putnam argues that traditional realism is beset with untenable metaphysical notions. Putnam supports a modified realism that

avoids the notion of an autonomous world and a metaphysically transcendent reality. Subsequently, Putnam avoids the Popperian belief that the "observer" implies anti-realism.

> . . . I am . . . in agreement with the thesis. . .which affirms that the micro-entities spoken of in quantum mechanics are as "real" as any entities knowable by us ("Quantum mechanics is the universal ontology"), while rejecting "Einstein's idea of the detached observer." There are real entities; <u>but which they are is relative to the observer</u>.[45]

Consequently, the abandonment of realism after the EPR tests was not imperative. Realism in general was not refuted by quantum theory or by the EPR experiments. In fact, it is questionable whether a metaphysical view such as realism could be actually tested. Nevertheless, <u>local</u> realist theories are in fact questionable after the EPR tests. Thus, realist views with empirical consequences are obviously more susceptible to falsification. Although it was desirable that Popper's realism possessed some concrete, empirical consequences, it was unfortunate that he could not accept realism without these tenets nor accept their empirical challenge. If realism remains a viable position, it appears that its content will be significantly different from commonsense realism.

Conclusion

Popper's philosophy of science represents a paradox. He advocated a flexible fallibilism coupled with bold conjectures. Popper thought scientists were not bound by any particular algorithm and thus could freely develop any falsifiable theory. He believed that the most successful intuitive notions were always susceptible to transformation

and science was essentially a perpetual quest for better theories and truths.

Yet, as we have seen, Popper's project in philosophical physics and his underlying ontology was conservative and biased with classical constraints. Thus, instead of offering a flexible realism with empirically sensitive tenets, Popper dogmatically and tenaciously affirmed his views despite opposing and highly confirmed evidence. For example, Popper countered that he "had not even abandoned locality" when dozens of tests revealed its violation. Popper's project and his response to its criticism revealed commitments to a priori presuppositions that needed critical reassessment. While the Copenhagen Interpretation of quantum theory represented a great breakthrough and achievement for many scientists and philosophers, Popper insisted in "pouring the new wine" of modern physics into the "old wineskins" of classical physics. While few doubt the revolutionary character of quantum theory, Popper attempted, on the contrary, to demonstrate its isomorphism to classical physics. While such attempt was not necessarily erroneous, Popper's impetus was an unrelenting fidelity to a classical ontology. Thus, Popper needed a flexible ontology and realism to complement his flexible "method" of bold conjectures.

Popper's realism also disregarded concrete theoretical and empirical contexts and made an unqualified claim of a "crisis without realism." In contrast, Michael Gardner has cogently argued that the realism-instrumentalism distinction makes sense only in the context of specific theories. In addition, it appears that theories often use instrumentalist postulates in the early stages of theory formation and

later realistically interpret the postulates after a period of successful usage. It is questionable then whether realist presuppositions are imperative in actual scientific practice or in theoretical development.

Despite Popper's liberal view of bold, counter-intuitive conjectures, his commonsense realism and pluralist ontology upheld classical, intuitive dichotomies. It appears unquestionable that without this allegiance to classical philosophical presuppositions, thinkers such as Popper, Einstein and Schroedinger would not have detested quantum theory. Yet, these classical presuppositions could have had a repressive and deleterious effect. Thus, epistemological and ontological norms derived from preceding theories could impede the development of wholly novel, counterintuitive ideas.

Finally, the fate of scientific realism is undetermined. While the assertion that "realism is dead" is extreme, it appears that classical realism (of classical physics) and Popper's commonsense realism are inadequate. In fact, Popper's realism clearly opposed a highly progressive research program.

On the contrary, Bohr's ideas will most likely contribute to a "new physical world view." For example, M. Fierz asserts,

> . . . the ideas developed by Bohr during the growth of quantum theory will not lose their leading character. I further expect that the new features characterizing Bohr's way of thinking, will even be more dominant in a new and better relativistic quantum theory. Such a theory will lead to physical ideas even more different from those of old.[46]

In contrast, Karl Popper essentially offers a classical world view with traditional distinctions and commonsense contraints that science and philosophy will probably not find advantageous nor enlightening.

Notes

[1] Roger Trigg, Reality at Risk (Totawa, New Jersey: Barnes and Noble Books, 1980) 153.

[2] Aage Petersen, Quantum Physics and the Philosophical Tradition (Cambridge, Massachusetts: M.I.T. Press, 1968) 8.

[3] Bas van Fraassen, The Scientific Image (Oxford: Oxford UP, 1980) 8.

[4] Michael Dummett, Truth and Other Enigmas (Cambridge, Massachusetts: Harvard UP, 1978) 146.

[5] Bas van Fraassen, op.cit., 12.

[6] Ibid., 12.

[7] Karl Popper, Objective Knowledge, (Oexford: Oxford UP, 1979) 323.

[8] Clifford Hooker, A Realistic Theory of Science (Albany, New York: State University of New York Press, 1987) 166.

[9] Karl Popper, op.cit., 203.

[10] Karl Popper, Quantum Theory and the Schism of Modern Physics (Totawa, New Jersey: Rowan and Littlefield, 1982) 103.

[11] Karl Popper, op.cit., 203.

[12] Andrew Pickering, Constructing Quarks (Chicago: U of Chicago P, 1984).

[13] Ian Hacking, Representations and Intervening (Cambridge: Cambridge UP, 1984) 22ff.

[14] Hilary Putnam, "A Philosopher Looks at Quantum Mechanics," Beyond the Edge of Certainty, ed. R.G. Colodny (Englewood Cliffs, New Jersey: Prentice-Hall, 1965) 79.

[15] Bernard d'Espagnat, In Search of Reality (New York: Springer-Verlag, 1983) 19.

[16] Karl Popper, Conjectures and Refutations (New York: Harper and Row, 1965) 99-100.

[17] Paul Feyerabend, "On a Recent Critique of Complementarity," Philosophy of Science 35 (1968): 92.

[18] Ibid., 94.

19 Karl Popper, *Realism and the Aim of Science*. (London: Hutchinson and Company, 1983) 57.

20 Paul Feyerabend, *Against Method* (London: Verso Editions, 1978) 86; see also *Science in a Free Society* (London: Verso Editions, 1982).

21 Ernan McMullin, "A Case for Scientific Realism," *Scientific Realism*, ed. J. Leplin (Berkeley: U of California P, 1984) 16.

22 *Ibid*., 16.

23 Karl Popper, *Objective Knowledge* (Oxford: Oxford UP, 1979) 33.

24 *Ibid.*, 34.

25 *Ibid*., 35.

26 *Ibid*., 39.

27 Karl Popper, *op.cit.*, 99.

28 *Ibid*., 26.

29 *Ibid*., 35.

30 Abner Shimony, "The Reality of the Quantum World," *Scientific American* Jan. 1988: 46.

31 J.L. Martin, *Basic Quantum Mechanics* (Oxford: Oxford UP, 1981) 173.

32 Bernard d'Espagnat, "Quantum Theory and Reality," *Scientific American* Nov. 1979: 140.

33 Imre Lakatos, "Methodology of Scientific Research Program," *Criticism and the Growth of Knowledge* ed. Imre Lakatos and Alan Musgrave (Cambridge: Cambridge UP, 1970) 203.

34 Karl Popper, *Quantum Theory and the Schism in Modern Physics* (Totawa, New Jersey: Rowan and Littlefield, 1982) 25.

35 *Ibid*., 25.

36 Karl Popper, *Objective Knowledge* (Oxford: Oxford UP, 1979) 118.

37 *Ibid*., 42.

38 Karl Popper, *Realism and the Aim of Science* (London: Hutchinson and Company, 1983) 124.

[39] Karl Popper, Quantum Theory and the Schism in Modern Physics (Totawa, New Jersey: Rowan and Littlefield, 1982) 2-3.

[40] Karl Popper, op.cit., 102.

[41] Bernard d'Espagnat, In Search of Reality (New York: Springer-Verlag, 1983) 94.

[42] Ibid., 12.

[43] Ernan McMullin, op.cit., 12.

[44] Ibid., 14.

[45] Hilary Putnam, "Quantum Mechanics and the Observer," Erkenntis 16 (1981): 218.

[46] M. Fierz, "Does a Physical Theory Describe an Objective, Singular Process," Observation and Interpretation ed. Stephan Korner (New York: Dover Publishers, 1962) 93.

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I was born in Kalamazoo, Michigan, in 1954. After attending Michigan State University and Western Michigan University, I received a Bachelor of Arts degree in philosophy in 1976. Several years later, I began the doctoral program in philosophy at the University of Florida. While working on the philosophy of science dissertation, I completed the entire undergraduate requirements of the mathematics and physics programs.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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